STATE OF THE ESTUARY

1992-1997

Vital Statistics
New Science
Environmental Management

San Francisco Estuary Project

SAN FRANCISCO BAY-SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

WHO, WHAT AND WHY ?

This *State of the Estuary* report describes the current status and health of the San Francisco Bay-Sacramento-San Joaquin Delta Estuary's environment — waters, wetlands, wildlife, watersheds and the aquatic ecosystem. It summarizes changes in our scientific understanding and management of the ecosystem since 1992, when the first *State of the Estuary* report was published. For the science, it draws on the 45 presentations and 68 posters of the October 1996 State of the Estuary Conference and on related research. For management, it draws on the 1996 *CCMP Workbook* — a review of progress made in Bay-Delta environmental management since 1993, when diverse interests completed the first consensus-based *Comprehensive Conservation and Management Plan* (CCMP) for the Bay-Delta. By combining overviews from the previous report, science from the conference and management notes from the workbook, this new 1997 report seeks to present a snapshot of the current state of the Estuary.

The report, conference and workbook are all part of the San Francisco Estuary Project's ongoing efforts to implement its CCMP and educate and involve the public in protecting and restoring the Estuary. The S.F. Estuary Project's CCMP is a consensus plan developed cooperatively by over 100 government, private and community interests over a five-year period and completed in 1993. The project is one of 28 such projects working to protect the water quality, natural resources and economic vitality of estuaries across the nation under the U.S. Environmental Protection Agency's National Estuary Program, which was established in 1987 through Section 320 of the amended Clean Water Act. Since its creation in 1987, the Project has held three State of the Estuary Conferences and provided numerous publications and forums on topics concerning the Bay-Delta environment. In the years ahead, the Estuary Project will be holding a 1998 conference and undertaking a complete update of its much more comprehensive 270-page 1992 *State of the Estuary* report.

WHAT'S INSIDE?

A NOTE ON CITATIONS

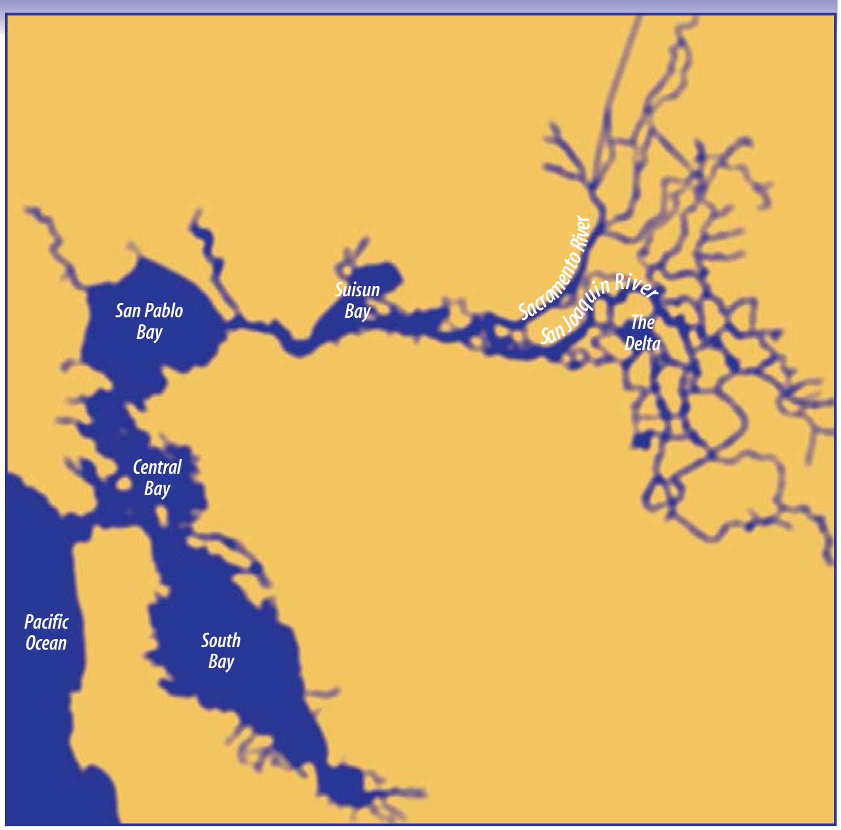
This report includes a mixture of unpublished and published research presented at the October 1996 State of the Estuary (SOE) conference (noted as "Author, SOE, 1996" with fuller references listed on pp. 58 & 60); summaries of other research (noted as "Author, Year" with a bibliography on p. 60); and information from various management agencies (noted as "SFEP" or "DWR," for example).

WHAT IS THE S.F. BAY-DELTA ESTUARY?

San Francisco Bay and the Delta combine to form the West Coast's largest estuary, where fresh water from the Sacramento and San Joaquin rivers and watersheds flows out through the Bay and into the Pacific Ocean. The Estuary came into being about the time humans arrived in North America. Around 12,000 years ago, the glaciers receded, the sea level rose and ocean waters rushed into the bedrock trough that forms San Francisco Bay. Over the next 10,000 years, the waters continued their inland migration. The Delta formed, not in the way that most river deltas build up from sediment deposition but as a sort of complicated lake. A bedrock barrier in the hills at the Carquinez Strait formed a natural levee. As sediments from the two great rivers accumulated behind it, a Byzantine network of 80 atoll-like islands and hundreds of miles of braided channels formed a huge marsh. A notch in the bedrock barrier allowed a stream of water and sediment to escape, forming San Pablo Bay.

In the 1830s, San Francisco Bay covered almost 700 square miles. By that time, it had evolved into a rich ecosystem; almost a million fish passed through, and 69 million acre-feet of water flowed down from mountain headwaters toward the sea. But in 1848 the Gold Rush began, and hydraulic mining plugged the rivers and bays with more than one billion cubic yards of sediments. Over time, farmers and city builders filled up more than 750 square miles of tidal marsh, and engineers built dams to block and store the rush of water from the mountains into the Estuary, as well as massive pumps and canals to convey this water to thirsty cities and farms throughout the state.

San Francisco Bay-Sacramento-San Joaquin Delta Estuary, California



Today's Estuary encompasses roughly 1,600 square miles, drains more than 40% of the state (60,000 square miles and 47% of the state's total runoff), provides drinking water to 20 million Californians (two-thirds of the state's population) and irrigates 4.5 million acres of farmland. The Estuary also enables the nation's fourth largest metropolitan region to pursue diverse activities, including shipping, fishing, recreation and commerce. Finally, the Estuary hosts a rich diversity of flora and fauna. Two-thirds of the state's salmon and nearly half the birds migrating along the Pacific Flyway pass through the Bay and Delta. Many government, business, environmental and community interests now agree that beneficial use of the Estuary's resources cannot be sustained without large-scale environmental restoration.

STATE OF THE ESTUARY 1992-1997

Taking stock of the state of the Estuary seems especially germane with a new century looming on the horizon. The last two centuries have been characterized by exploitation and alteration of the Estuary and the resources within its watersheds — from gold mining and logging in the late 1800s to water development and large-scale farming in the first half of the 1900s. It is only in the last decades, since the wave of clean air and water and wildlife protection laws of the 1970s, that conserving and protecting the environment has become a priority. And it is only in this last and final decade that the push to preserve specific species, wetlands and resources has matured into a desire to sustain and even restore whole biological communities and ecosystems.

In this context, this summary examines the state of the Estuary in terms of the state of the "resources" themselves, as well as the degree to which efforts are underway to understand, protect and improve the health of the ecosystem.

At the most basic level, our Estuary's "health" comes down to the state of its waters, wetlands and wild things. Comparing today's (1996-1997) state to yesterday's (1992), there's both good and bad news. On the good side, we have enhanced, restored or protected (through public purchase) substantial tracts of wetlands; cleaned up and improved conditions in numerous creeks and watersheds; and reduced selenium, copper and rice-pesticide discharges to waterways. Populations of endangered California clapper rails and winter-run Chinook salmon seem to have stopped declining and may even be slowly increasing. Fish in Bay creeks are maintaining healthy populations. Waterfowl and shorebirds continue to stop over in large numbers. Freshwater flows for environmental purposes have been easier to come by with the recent wet weather.

Janet Delaney

On the bad side, the vital phytoplankton that sustains invertebrates and juvenile fish is being consumed at alarming rates by the invading clam *Potamocorbula amurensis.* The rate of invasions by such foreign species is on the rise, as is their alteration of benthic communities and fish assemblages. Meanwhile Chinese mitten crabs are creeping toward the Delta, where their burrowing could undermine levees, and Atlantic zebra mussels, known to clog water intakes, have appeared at our borders. Species-wise, take limits of the endangered Delta smelt at the water project pumps have been exceeded several years running, harbor seal populations in the Bay have not increased since governmental protections as have coastal populations and introduced predators, such as red foxes and feral cats, pose increasing threats to sensitive shorebirds. Pollution-wise, levels of many contaminants frequently exceed water and sediment quality guidelines, and long-banned PCBs and DDT persist in the environment. Indeed, PCBs, dioxin and mercury have accumulated in Bay fish to levels that pose a potential human health risk.

ENVIRONMENT

"We've made dramatic progress in water policy, and in the amount of water coming into play for the environment. It's also been a bad time to be a big old-style water engineer — the Auburn Dam and a new big peripheral canal were both declared dead in 1996. But for every step forward we take two steps back. There are lawsuits and challenges all the way. At least massive environmental restoration is now recognized by all as necessary."

BARRY NELSON
Save the Bay

1996 State of the Estuary Conference

SCIENCE

"Our recent shift from single magic-bullet theories to complex, ecological multi-factor models is going to make it harder to get policy folks to follow."

BRUCE HERBOLD
U.S. Environmental Protection Agency

1996 State of the Estuary Conference

ECONOMY

"Permit uncertainty and delay is still stifling our ability to do business in a Golden Age of world trade and to use the Bay as an economic generator for the region. A strong economy supports environmental protection and can fund scientific research and acquisition of refuges. We could be doing more to improve the permit process and to weave the economic part of the equation into environmental plans and policies."

ELLEN JOHNCK
Bay Planning Coalition

1996 State of
the Estuary Conference

POLITICS

"We still need to draw a relevance between preservation of the Estuary and the quality of people's lives and involve local government officials in the call to action. We need more diversity in our effort to protect the Estuary."

REUBEN BARRALES
San Mateo County
Supervisor & BCDC
Commissioner

1996 State of
the Estuary Conference

Beyond the resources themselves, the state of the Estuary can also be measured in terms of well-intentioned effort, which has certainly increased since the early 1990s. A host of earnest, public-private and government programs have been launched, and some implemented, that reflect the public's commitment to environmental health — one to develop a long-term management strategy for Bay dredged material (LTMS), another to double anadromous fish populations and improve water conservation and environmental conditions in the area served by the Central Valley Project (CVPIA), some to balance water use and supply conflicts (Bay-Delta Accord & CALFED), and others to better monitor estuarine pollution levels (RMP) and map Bay wetlands (San Francisco Bay Area Wetlands Ecosystem Goals Project). Recent years have also seen a wave of new projects and programs tackling some of the Estuary's thornier pollution problems — stormwater runoff from cities, farms and construction sites; metal leaks from abandoned mines; air and road dust from vehicles. And restoration of habitat has never been so well-funded.

These programs — if fully implemented — may go a long way toward addressing the five critical Bay-Delta management issues identified by the Estuary Project in the late 1980s — the decline of biological resources, the diversion and alteration of freshwater flows, increased dredging and pollution, and intensified land use — another measure of the state of the Estuary. Of the five, only the land use issue remains unaddressed on a large scale, although piecemeal efforts to reduce stormwater impacts from new construction and to provide planning tools for local government are underway. According to a 1996 Estuary Project report card on Bay-Delta environmental management, 59 (40%) of the CCMP's 145 actions to protect fish, wildlife, wetlands and watersheds have had moderate to full implementation since 1992.

Finally, the state of the Estuary may also be measured in terms of understanding the nature and value of the ecosystem. Many more people — scientists, educators, citizens and resource managers — are involved in researching and monitoring estuarine conditions and health than in the 1980s. The large environmental planning projects described above have expanded the dollars and time committed to getting good science to back up management decisions. In addition, there's been a recent push to better map and document the Bay's remaining wetlands and marsh life using GIS technology and to offer at-your-fingertips electronic access to data on real-time estuarine conditions — from where the endangered fish are swimming to flow and salinity levels. There's also been a blossoming of community and school-based programs that use citizens and students to collect stormwater and creek data for municipalities. Despite this swell of data and knowledge, our understanding of how the estuarine system works and responds to management changes is still far from complete.

All these measures of the state of the Estuary fall short of offering a consistent, meaningful long-term standard of the ecosystem's health. Such a standard, and a set of defensible indicators for evaluating the state of the Estuary in the new century ahead, are still being developed. In the meantime this report, and the three conferences and 1992 report that preceded it, offer useful snapshots of the State of the Estuary over the last decade.

1 FRESHWATER FLOWS

A Martinez monitoring station, where Department of Water Resources engineer Hank Gebhard checks water quality and hydrologic data collected by top and bottom sensors in the Estuary.

The amount of fresh water flowing into the Estuary from rivers, streams and runoff exerts a strong influence on environmental conditions. The volume and timing of freshwater inflow affect estuarine circulation patterns, water quality and the abundance of many species of fish, plants and other organisms.

Courtesy Water Education Foundation

Harvey Banks Pumping Plant

Before dams, canals, pumps and other water development facilities were built in the Estuary's watershed, the volume and timing of freshwater inflow were determined by natural hydrological conditions. Peak volumes of winter and spring runoff, combined with a vast acreage of wetlands and some 6,000 miles of instream habitat, provided conditions for a diverse estuarine ecosystem. At that time, there were far fewer threats to the Estuary's health than today.

Beginning in the early 1900s, water development for flood control, agricultural and municipal uses altered the volume and timing of freshwater inflows. Today, major reservoirs in the Central Valley reduce the amount of water flowing to the Estuary in winter and spring and increase it during the summer and fall. Diversions to cities, farms and other uses remove an average of more than half the water that would otherwise reach the Bay. Though about 70% of the state's available water supply is carried by Northern California rivers and streams, 80% of the present demand for water comes from the San Joaquin Valley and south of the Tehachapi Mountains (the Los Angeles area).

The total volume and timing of fresh water reaching the Estuary were and are highly variable, primarily as a result of changing precipitation. During the past 60 years, annual inflow has ranged from more than 60 million acre feet (MAF) to less than 6 MAF and averaged about 23 MAF. More than 14 MAF are currently diverted from the Estuary's supply. Though the majority of this water is now used for agriculture, demand from California's growing cities and suburbs is on the rise.

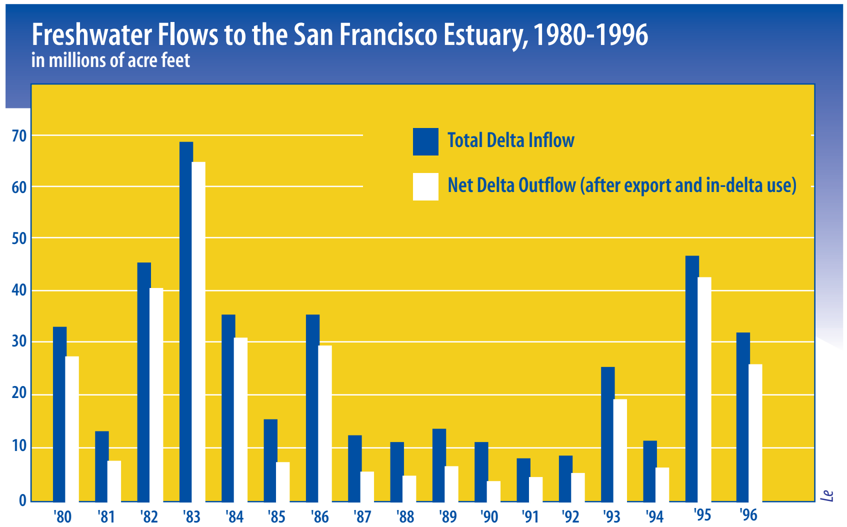
Water development has affected many of the Estuary's biological resources. For economically important striped bass and salmon, and for other fish species, water diversions and exports have reduced the quantity and quality of spawning and rearing habitat, entrained eggs and young and increased mortality by interfering with migration routes. More subtle and less well-understood effects of water development include the removal of nutrients, phytoplankton and zooplankton at Delta diversions and the influence of altered flows on benthic biota. In general, the effects of diversions and altered flow regime are greatest during dry years.

In the 1990s, increased recognition that water development is contributing to the Estuary's environmental problems has resulted in short- and long-term efforts to better balance water use for both human and environmental purposes. In 1994, state and federal officials signed a three-year accord that led to the establishment of new water-quality standards and flows for fish in the Delta. The accord also set in motion an ambitious cooperative effort to develop a long-term plan for more balanced management of the Bay-Delta ecosystem: a plan designed to improve water flows, storage and timing for the benefit of all users.

STATUS REPORT

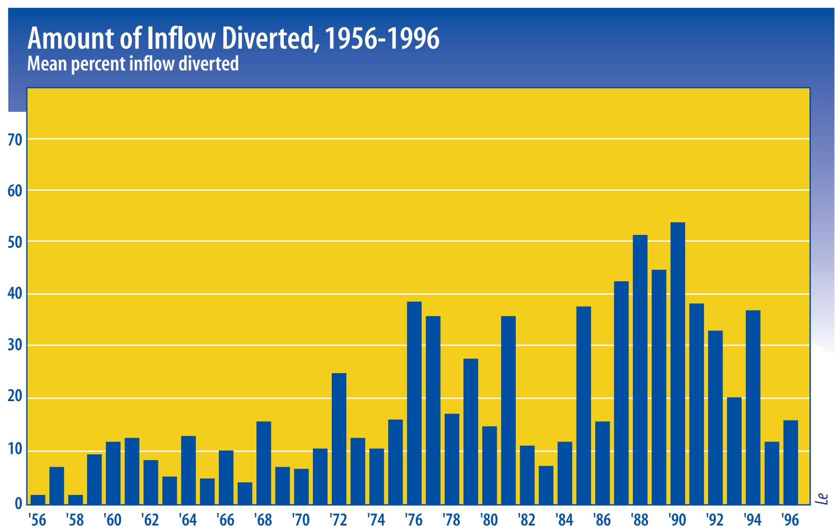
RECENT INFLOWS

Recent years have been much wetter than those of the 1987-1992 drought. Wet or above normal rainfall years in 1993 and 1995-1996 greatly improved flows. In recent years, inflows to the Delta and Estuary (after upstream diversions) were 32 MAF in 1996, 47 MAF in 1995, 11 MAF in 1994 and 24 MAF in 1993. Major inflows to the Delta in 1996 included 23 MAF from the Sacramento River, 3.9 MAF from the San Joaquin River and 3.4 MAF from the Yolo Bypass. DWR



DIVERSIONS FOR BENEFICIAL USE

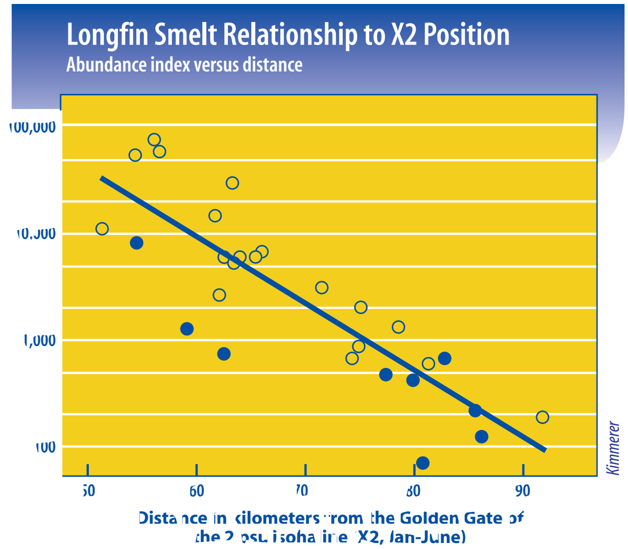
The Estuary's freshwater supply irrigates over 4.5 million acres of farmland and provides drinking water to over 20 million people, as well as sustaining fish, wetlands and riparian systems. To supply cities and farms, fresh water is diverted both within the Delta and upstream of the Delta in the Estuary's watershed. Depletions of upstream supplies are estimated at about 9 MAF per year; in-Delta exports were 5.2 MAF in 1996, 5 MAF in 1995, 4 MAF in 1994 and 4.6 MAF in 1993 ("DAYFLOW" model data, which include diversions by state and federal water projects, North Bay aqueduct, Contra Costa Water District and in-Delta users). Delta export levels have largely remained within the range of 4-6 MAF per year since 1974. The annual mean percent of total Delta flows diverted between 1992-1996 ranged from a low of 11% in 1995 to a high of 36% in 1994. The largest diversions on record occurred during the 1987-1990 drought years — almost 54% of inflow was diverted in 1990. DWR



WATER RECYCLING

Municipal and industrial water recycling and reclamation help reduce the demand on the Estuary's limited water supply. The total amount of water recycled in the Bay Area grew from 31,000 acre-feet in 1992 to 40,115 in 1995. The Sacramento hydrologic region recycled approximately 12,480 acre-feet in 1995, and the state as a whole 450,000 acre-feet. Inland recycling has its benefits and drawbacks, as recycling wastewater that would normally augment river flows may reduce flows (as well as pollutant levels) and change water temperatures. Recycling activities on the books for implementation in the Delta service area (most of the state) early next century are impressive: a 90,000 acre-feet increase online by the year 2000 swelling to 1.2 MAF by the year 2020. DWR

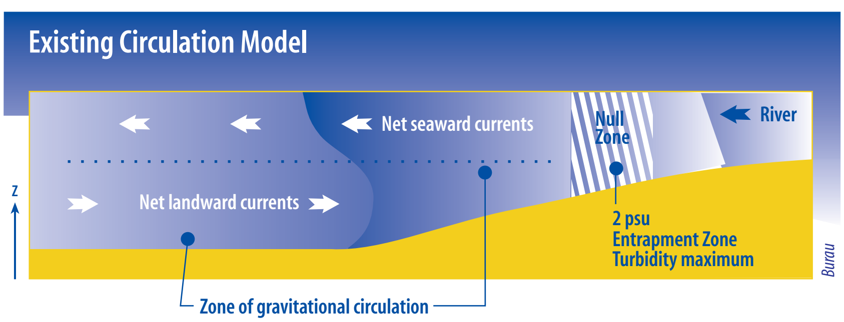
SALINITY & SPECIES ABUNDANCE

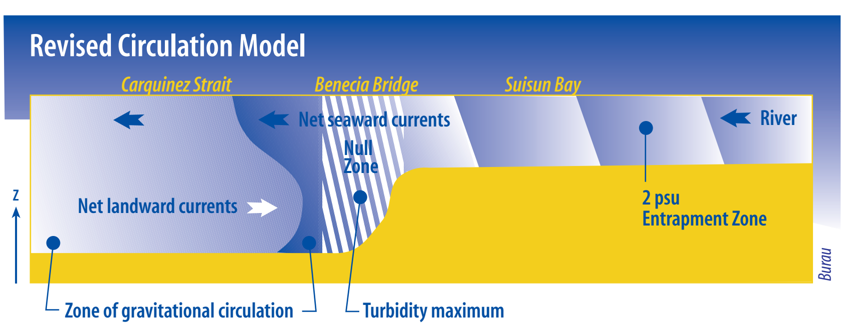


The abundance of many estuarine species has a strong, positive relationship with freshwater flows. Data show that historical locations of the 2 psu near-bed isohaline (a line in the Estuary connecting points of equal salinity and measured in terms of practical salinity units — or "psu" — a line also referred to as "X2") are related to abundance and survival of many organisms at different levels of the food chain, including phytoplankton, bay shrimp and longfin smelt. Most species studied increased in abundance as a simple function of greater outflow and reduced salinity (Armor et al. 1992). These scientific findings helped structure new state water-quality standards for the Estuary (see p. 9). However, since the spread of the non-native clam *Potamocorbula amurensis* in 1987, relationships of organisms lower on the food chain to outflow have changed or disappeared, probably because of grazing by this efficient filter feeder (see p. 20).

INFLUENCES ON NET FLOW

Tides, river inflow and diversions all interact with wind and the bottom topography to determine the net flow direction of estuarine waters (upstream or downstream), whether flows stratify into two layers moving in different directions, and what the strength and duration of flows will be. Despite the fact that recent years have been very variable in terms of rainfall and river outflow, net (non-tidal) bottom flows were basically seaward (down Estuary) within Suisun Bay during the springtime of all four years. By contrast, strong landward (up Estuary) bottom flows have been observed just seaward of Suisun Bay in the Carquinez Strait. The likely reason for this contrast is the difference in bottom topography — Carquinez Strait is 20 or more meters deep, and Suisun Bay is only 10 meters deep. In the channels of Suisun Bay, landward near-bed flows only occur in weak, short-lived pulses that occur during slack tidal periods — pulses of insufficient strength and duration to create a net flow upstream. The greater depth of the Strait, however, allows longer and stronger landward near-bed pulses — resulting in net upstream bottom currents. As a result, stratification is weaker in Suisun Bay, while in the deeper area of the Strait, the water stratifies into two-layer flow — with lighter, fresh water moving downstream on top, and heavier salt water moving upstream on the bottom. This two-layer flow — also known as "gravitational circulation" — is probably strongest in Carquinez Strait except during extremely high outflows (Burau, SOE, 1996).





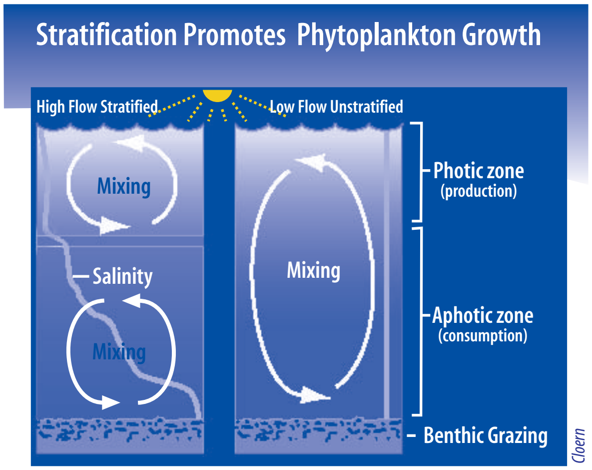
NULL ZONE LOCATION

Contrary to prior models, the Estuary's "null zone" — the location where landward- and seaward-flowing bottom currents converge — is now believed to be only weakly linked to the 2 psu isohaline. Instead, its position is controlled partly by the movement of the salt field, and partly by the bathymetry of the Estuary. A null zone occurs near the Benicia Bridge throughout much of the year, where the change in depth produces upwelling and a maximum in turbidity. Null zones may also occur in the northwest end of Suisun Bay along the mothball fleet, east of the Suisun Cutoff and in the lower Sacramento River, whenever salinity is above 2 psu at these locations. Consequently, the Estuary's null zone is not necessarily located in the same position as the "entrapment zone" (EZ). The latter refers to a place, usually in the vicinity of 2 psu, where nutrients and biota accumulate. In some other U.S. estuaries, many of which have weaker tides and relatively constant depths, the null zone is physically associated with an entrapment or maximum turbidity zone. In the S.F. Estuary, null zones may occur near or quite far from the entrapment zone, which is usually positioned in Suisun Bay in spring and summer — suggesting a more complex model in which flow-driven shifts in the Estuary's salinity gradient interacting with the Bay's bottom topography determine stratification and the extent of gravitational circulation. The complex interactions between movement of the salt field, gravitational circulation and retention of particles and organisms in the EZ are now being studied (Kimmerer & Burau, SOE, 1996).

EZ PRODUCTIVITY

Three factors, perhaps in combination, may be contributing to the pronounced concentration of organisms near the 2 psu isohaline: the weak tidal pulses described above, the exchange of waters between Suisun Bay's channels and the adjacent shallows of Honker and Grizzly bays (rich fish nursery grounds), and vertical tidal migration. To date, research has only confirmed the influence of the latter. Tidal migration refers to how certain organisms use the tides to position themselves in the Estuary. Studies examined the relationships between the positions of organisms — in terms of their height in the water column and location upstream or downstream of the EZ — and physical parameters like tidal flow, river flow and time of day. Results indicated that most organisms ride the higher velocity near-surface currents on flood tides upstream then drop down to the lower-velocity layers on the ebb — and thus behave in a way that maintains their position within range of the EZ (Kimmerer & Burau, SOE, 1996).

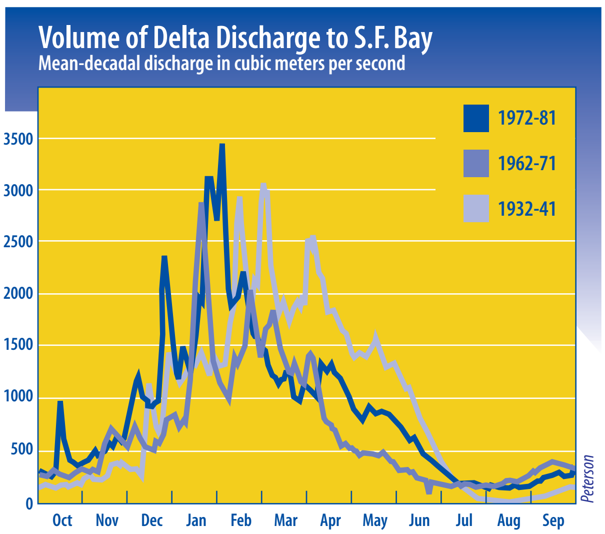
FLOWS AS ESTUARY LINKAGE MECHANISM

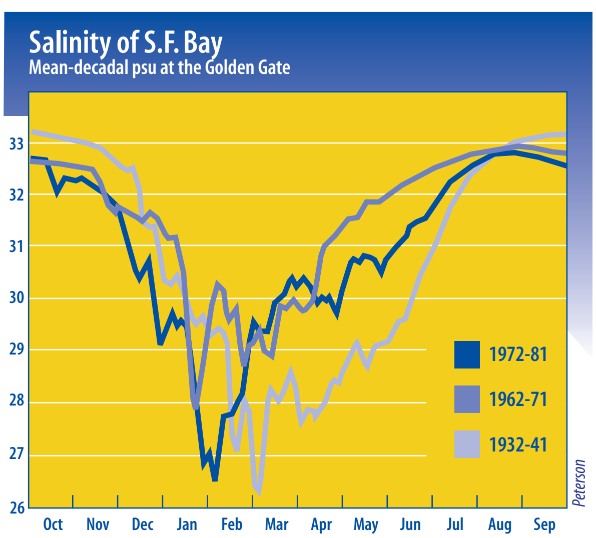


River flow is a key mechanism linking different sub-embayments in the Bay-Delta system, and the variability of flow is an important cause of variability in the state of the Estuary. High freshwater flows from the Delta cause a cascade of physical, chemical and biological responses far downstream in the South Bay. Such South Bay responses include establishment of salinity stratification (layering of fresh and salt water), which slows the rate of vertical mixing in the water column. This in turn stimulates the production and population growth of phytoplankton in the fresher, sunlit upper layers, causing large changes in water chemistry (e.g., concentrations of oxygen, nutrients, trace metals and organic compounds) and supporting rapid growth of mussels, clams and other invertebrates. Thus high flows influence not only the health of upstream fish and habitat, but also the biological productivity and recruitment of fish in the Delta and Suisun Bay, and the productivity and water quality of the South Bay far downstream. The strength of this linkage varies between wet and dry years and with seasonal changes in flow. The Delta, North Bay and South Bay are linked components of one ecosystem, and management strategies to restore, protect or enhance the Estuary should be based around this broad ecosystem perspective (Cloern, SOE, 1996).

DELTA DISCHARGE HISTORY

Spring Delta discharge to S. F. Bay has declined since 1932, accompanied by salinity increases at the Golden Gate. Though data do not extend far enough back in time to show how the system evolved from purely natural conditions to its present regulated state, the Yosemite National Park (YNP) discharge offers a useable "pristine" measure of natural conditions. YNP is far upstream from the Bay, but its discharge is broadly representative of the overall Sierra snowmelt-runoff that is a strong contributor to the natural (April-June) discharge "signal" seen by the Bay-Delta system. Also, because most water development didn't begin until the 1930s, observations from that time, with qualifications, represent a less-altered regime downstream from YNP for tracing some of the overall changes in discharge to the Bay. To illustrate this change, daily YNP flows were compared with San Joaquin River discharge at Vernalis, using decadal averages of the daily discharge rates to minimize effects of wet and dry years. From 1932 to 1941, a strong YNP snowmelt signal was present in the San Joaquin River discharge at Vernalis, with YNP representing about one-tenth the amplitude of the river. In the following decades — 1942-1951, 1952-1961 and 1962-1971 — the spring peak was nearly constant in YNP, but continuously decreased in the San Joaquin River, presumably owing to impoundment and withdrawal. By 1972-1981, a period of decline in Bay fisheries, the YNP peak all but disappeared from the river discharge. This long-term reduction in spring discharge is consistent with a long-term spring rise in salinity near the Golden Gate, a location that has a near-linear salinity response to variations in Delta discharge. A decrease in discharge of approximately 1,000 cubic meters per second is equivalent to a rise in approximately 3 psu at the Golden Gate (Peterson et al., SOE, 1996).





COASTAL OCEAN INFLUENCES

Conditions in the coastal ocean — wind direction, the spring upwelling of deep ocean water and El Niño events (warm winds and currents that occur every three to seven years) — all modulate sea level and the Bay's response to freshwater flows from the Delta. Northerly winds drive surface water out of the Estuary, for example, while southerly winds drive water in. In records of the past 100 years, a positive correlation exists between alongshore wind direction and stress and adjusted sea level: Wind stress to the south (northerly winds) decreases sea level, whereas wind stress to the north (southerly winds) increases sea level and drives ocean water inland. In addition, sea level correlates with temperature. Sea level rises in the fall or during El Niño as the result of heating, and drops in the spring when southerly wind stress brings colder, saltier upwelled water from the deep ocean to the surface — drawing down surface water from the Bay. These changes in coastal hydrologic and atmospheric conditions affect salinity patterns in the Bay (Ryan et al., SOE, 1996).

SPRING ATMOSPHERIC INFLUENCES

Two features of natural climate variability have an overriding influence on freshwater flows: the wind patterns along the coastal ocean and air temperature/snowmelt in the High Sierra. The switch from winter to spring winds correlates with a drop in sea-level height typically accompanied by the cessation of winter storms and the beginning of spring warming, followed by snowmelt-driven discharge from the Sierra. Based on a multi-year series of atmospheric circulation and surface temperature anomalies, this switch tends to be caused by a super-regional-scale weather system in which, over a 5-10 day period, low pressure offshore is replaced by anomalously high pressure over the West Coast. Such spring regional weather patterns often encompass both the oceanic and upstream watershed boundary of the Bay (Cayan et al., SOE, 1996).

Gerry Mooney, courtesy Cargill Salt

CLIMATE CHANGE

Greenhouse gas build-up may reduce the state's water supply by intensifying warming in the winter, when California gets 80% of its snow and rainfall. The snowpack may melt sooner, and much of what falls as snow may fall as mid-winter rain instead — taxing the ability of reservoirs to protect downstream regions from flooding and leaving them unable to meet agricultural demands later in the season. Downstream, lower summer runoff could increase pesticide and heavy metal concentrations. In addition, models predict a sea level rise of 2-3 feet in the next 100 years, which would cause sea water to move farther upstream into freshwater marshes and water supplies (IPCC 1996).

RECORD HIGH FLOW IMPACTS

The storms and floods of January 1997 resulted in one of the highest-ever flows through the Delta on record (16 MAF — substantially more than previous flood records of 10 MAF in February 1986 and 12 MAF in January 1970). These record flows produced a marked "freshening" of the Bay, with salinity lower than any measured over the past 30 years. The surface salinity in the Central Bay — normally the saltiest part of the Bay due its proximity to the Golden Gate and Pacific Ocean — went down to 7 psu in January as compared to 32 psu (nearly oceanic salinity) in November 1996 (see *http://sfbay.wr.usgs.gov/access/wqdata/index.html*). Salinity stratification also increased, with bigger differences between surface and bottom salinity than in previous years. This stratification may have contributed to an earlier-than-normal spring bloom of phytoplankton in the South Bay (Cloern, Pers. Comm.). Fresh conditions and high flows may have also contributed to a very unusual distribution of zooplankton Baywide in January, with freshwater species that may have originated in upstream reservoirs turning up in the Central Bay (Bollens, Pers. Comm.).

For more information on flows, salinity and sediments, see Schemel p. 54, and Shum and Gartner p. 55.

SCIENTIFIC PERSPECTIVE

WHAT WE'VE LEARNED ABOUT FLOWS

DR. WIM KIMMERER
Biological Oceanographer
Romberg Tiburon Center
San Francisco State University

Transcript of Summary of State of the Estuary Conference Flows Presentations

"Where a particular salinity occurs is completely dependent on flow. There is a lot of lag in it. It's sort of like a shock absorber: The salinity distribution of the Estuary absorbs a certain amount of variability in flow. But in the long term, if you increase flow, you'll push this salt gradient downstream.

"We've used the position of two parts per thousand or two practical salinity units of salinity as an index of flow. We're actually using this variable in management now. This variable, which we call X2, is the tidally averaged distance of the two parts per thousand isohaline from the Golden Gate. During the 1976-1977 and early 1990s droughts, this two parts per thousand isohaline moved right up into the Delta, well above the confluence of the Sacramento and San Joaquin rivers. During the 1983 floods, it moved down beyond Martinez into the Carquinez Strait.

"Now one of the things that we've learned recently is how flow interacts with tides to affect the movement of particles and organisms in an area of the Estuary called the Entrapment Zone. A previous conceptual model of that region, which occurs in or near Suisun Bay, is now quite outdated. This model held that tidally averaged flow at the surface was seaward, and flow at the bottom was landward.

"The net or tidally averaged flow at the surface is down the Estuary, which it has to be because of the river input. But the interesting thing is that in Suisun Bay, the flow at the bottom is also down Estuary, and it never reverses. So the two-layer flow conceptual model we had before doesn't work there. The USGS has had some instruments out now for fairly long periods in several different years and different water-year types, and in Suisun Bay, we have not seen any substantial gravitational circulation.

"The flow picture at the Benicia Bridge, where the water is a whole lot deeper, is a little bit more complicated. The flow at the bottom still oscillates with the tides but the up-Estuary component is stronger than the down-Estuary component, whereas at the surface the down-Estuary component dominates. What this tells us is that the water depth is extremely important in interacting with the tides to determine which way the water is going to flow and how the water stratifies. Up in Suisun Bay, the stratification is pretty much wiped out by the strength of the tidal currents in that shallow part of the Estuary. In the deeper part of the Estuary such as the Carquinez Strait, the shear due to tidal currents isn't quite strong enough to generate turbulence that can overcome stratification. And so we get stratification, and we get this two-layered flow.

"Well, what does stratification do? In the South Bay we've got a really nice story about the effect of stratification on the production of phytoplankton or primary production. We measure phytoplankton abundance or biomass as chlorophyll. What we see in the South Bay is that when salinity drops in spring because of inflows from various locations, we get these tremendous peaks in chlorophyll. And what is going on is that the water is stratifying. The phytoplankton are essentially trapped in the surface layer, and they get more sunlight. Remember it's a turbid estuary — when phytoplankton are down near the bottom, they don't get enough light. The phytoplankton at the surface are also isolated from the grazers on the bottom when the water column is stratified. During these times, they grow extremely rapidly for a rather short period of time. Now, one of the linkages that's apparent is that some of this flow comes from the local creeks in the South Bay, but a lot of it comes from the North Bay. This means that the whole Bay is tied together by flow through hydrodynamics, stratification and influences on biota.

"Most of the estuarine species have some relationship with flow, and every single one of them is positive, at least below extreme flood conditions. These relationships don't occur necessarily because of their food supply. In other words, in most estuaries we see relationships like this, and they occur because more flow brings more nutrients in. You get more production of phytoplankton and more zooplankton growth, and then more fish growth. We don't think this is the case in the San Francisco Estuary, even though we see stimulation of phytoplankton in the South Bay. We think the productivity is more directly related to physical habitat. In other words, it's a case of flow interacting to produce a salinity gradient at a certain location. The bathymetry of the Bay is such that this provides habitat."

Management Changes

DELTA STANDARDS

Federal, state and local interests agreed to X2 as a water-quality standard to protect the Delta environment under the 1994 Bay-Delta Accord and the resulting 1995 state water-quality plan. This standard limits the upstream movement of the 2 psu isohaline — often referred to as X2. Adequate flows must be released to keep X2 within a certain range of positions in the Estuary near the Carquinez Strait, positions associated with abundance in fish and biota. Diverse scientists developed the rationale for the X2 standard at workshops organized in the early 1990s by the S.F. Estuary Project. Since the Accord, conditions have been wet — requiring little water project operation or releases to meet the X2 requirements and alleviating any potential conflicts with other uses. Spring 1995 was so wet that no special pump management was needed. A temporary dry-up in April 1996 required just a few days of project operations to meet X2 before a new storm arrived. In 1997, early heavy rains generated plenty of outflow to meet X2. However, the subsequent spring dry-up required some X2 management by late May or June. The location of X2 is now part of regular monitoring and reporting on the state of the Estuary.

Mikki Ferrill, Courtesy EBMUD

Kids tour East Bay MUD's San Leandro Water Education Center —built in 1996 to inform homeowners and other consumers about water recycling and conservation. The center features 28 displays and is part of EBMUD's efforts to reduce area water consumption by 33 million gallons by the year 2020 through conservation and recycling. Other efforts include changing water-wasting toilets to ultra-low-flow models using as little as 1.5 gallons per flush and using recycled water for industrial cooling and large landscape irrigation customers like golf courses and parks.

PUMP OPERATIONS COORDINATION

The first-ever federal-state operations group of water managers and scientists was established in 1995 to make day-to-day decisions about pumping and water-resource management to minimize loss of endangered species, maintain X2, meet flow requirements of the Bay-Delta Accord and the state water quality plan, minimize negative environmental impacts and provide for reliable water supplies. This body is called the "CALFED OPS" Group. Though this group's work has been made easy by several wet years in a row, its existence has already proven to be a valuable vehicle for fine-tuning and coordinating management of the Estuary's limited freshwater supplies.

CALFED CREATION

The cooperative CALFED Bay-Delta Program was created in 1995 to develop a long-term solution for balancing all beneficial uses of Estuary waters. Since being established, CALFED has developed three basic storage and conveyance alternatives, including various actions that would change how fresh water is channeled, managed and stored. Alternative 1 would make little or no change to the current system of moving water through the Delta. Alternative 2 would dredge and reconfigure some Delta channels. Alternative 3 would combine some Delta channel improvements with construction of a new man-made channel, or some other "isolated facility," with a capacity of 5,000-15,000 cfs. Beyond these efforts to enhance management flexibility with regard to flows and deliveries, the alternatives also present a variety of storage scenarios, pumping changes and water-efficiency and transfer programs — all of which have the potential to alter the hydrology and ecology of an already heavily modified estuarine system. The three alternatives will soon undergo environmental impact review.

WATER EFFICIENCY

Water conservation planning has increased through a variety of laws and several memoranda of understanding (MOUs). The newest MOU is one in which at least 22 agricultural water districts to date have agreed to undertake efficient agricultural water management practices. A similar style MOU was developed for urban water conservation efforts in the early 1990s and has since been signed by at least 100 districts. Beyond the MOUs, the Central Valley Water Project now requires the 100 districts that use its water to meet new tougher 1993 criteria in water efficiency and management planning. Of these, 50 had plans meeting the new criteria as of spring 1997. State law, meanwhile, requires all urban districts to submit water conservation and demand reduction plans (265 out of a possible 400 now have plans on paper). Lastly, recent amendments to the California water code prohibit the use of drinking water for watering parks, cemeteries, golf courses and highways. In addition, any public agency may now require the use of reclaimed water for residential landscape use. While all of these agreements and planning efforts should help conserve water and reduce demand, few have strong enforcement or follow-up components. Two other activities that could greatly reduce demand — retiring farmland on a large scale and reducing water subsidies to agriculture — remain perpetually contentious.

INCREASING DEMAND

Statewide, a swelling population is expected to increase urban water demand from 6.8 MAF in 1990 to 10.5 MAF by 2020, even after accounting for water conservation measures. Irrigated agricultural acreage is expected to decline statewide, largely due to urban encroachment, as well as to land retirement in the San Joaquin Valley. Such acreage reductions and increased water efficiency are expected to reduce agricultural demand by 2 MAF statewide by 2020. Demand for water for environmental uses (wetlands, wild and scenic rivers, fisheries, etc.) was around 24 MAF statewide in 1990 and is expected to increase. At least two-thirds of statewide demand has historically been supplied by the Bay-Delta watershed.

2 FISH & THE AQUATIC ECOSYSTEM

Cal Fish & Game biologist (Kathy Hieb) and crew (Kent Hespeler and Matt Kondratieff) on the research vessel Longfin *conduct seasonal sampling of bottom-dwelling and pelagic fish, as well as shrimp and crab in the Bay.*

The Estuary has sustained a productive aquatic ecosystem for millennia — a system enriched by the influence of both ocean tides and fresh river waters. But the Estuary's aquatic habitat has been severely altered by human development in the last century, specifically by water supply, navigation and flood-control projects. The extent of the Bay's open water has been reduced by one-third, and valuable wetland and shallow-water habitats have been drastically diminished. As a result of habitat change and other human-induced causes, the Estuary's ability to support a diverse ecosystem with large populations of economically important fish and shellfish species has declined.

Since the mid-1970s, major changes in the aquatic food web have been occurring in the Estuary's northern reach. Phytoplankton abundance — at the base of the food chain — has declined. One recent cause is the establishment of large numbers of the unintentionally introduced clam *Potamorcorbula amurensis* in Suisun Bay, which may have reduced the availability of food for fish. *Potamocorbula* has also rapidly altered the community of bottom-dwelling organisms, with potentially far-reaching effects on fish and wildlife.

Janet Delaney

Higher up the aquatic food chain, the number of Chinook salmon returning to spawn in the Estuary's tributaries has declined considerably. In the Sacramento River, the winter-run salmon has been designated a federal and state endangered species. This run reached an all-time low in 1994 (189 fish) but recovered a bit with wet weather and good ocean conditions in 1995 and 1996 (900 fish). Although salmon continue to support valuable commercial (ocean) and sport fisheries, many of today's catch originates in hatcheries. Meanwhile, the population of the popular sport fish striped bass is at its lowest level since this species was introduced more than 100 years ago. Delta water diversions, pollutants and habitat alteration are suspected causes of this decline.

Since the early 1980s, the number of Delta smelt, a once-abundant native species of the Delta and Suisun Bay, has declined to low levels. In 1993, smelt were listed as a federal and state threatened species. Scientists are still uncertain as to exactly what conditions help smelt thrive.

Fish in Bay creeks may be doing a little better. A 1994-1997 survey (see "Native Fishes" p. 16) suggests that at least 75% of fish species native to Bay creeks are maintaining healthy populations. Scientists attribute the halt in degradation to stepped-up Clean Water Act enforcement and stormwater control over this last decade, as well as to watershed protection efforts and community creek clean ups and restoration.

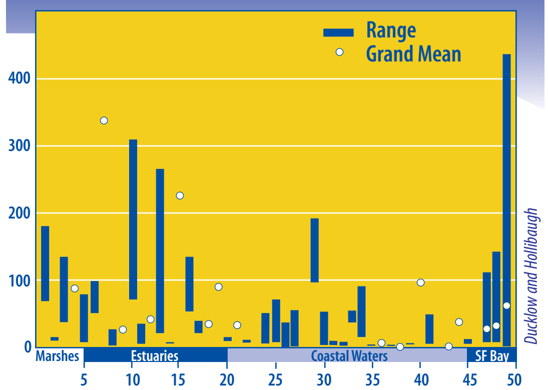
Wet weather and new laws and agreements made in the mid-1990s have helped the Estuary's endangered fish. The Central Valley Project Improvement Act and the Bay-Delta Accord both provide for improved flows and habitat for fish, and the CALFED program promises to come up with a long-term approach to balancing the demands of both humans and fish on the Bay-Delta system. If the promise of these activities is fulfilled, the health of estuarine organisms could further improve.

STATUS REPORT

SOURCES OF FOOD

The abundance and growth rates of bacteria — key to the cycling of organic matter at the base of the estuarine food web — suggest that S.F. Bay has limited food availability compared to other estuaries. The biomass of bacteria in the Bay (a standing crop of 230,000 kg of total organic carbon Baywide) is equivalent to an estimated 60 Humphrey (the Humpback Whale) Units, with a population-doubling time averaging 1.2 days. The surface area of these cells is approximately 20 times that of the surface area of the Bay itself — constituting the largest biologically active surface in the Estuary. Bacteria are key agents in processing DOM and POM (dissolved and particulate organic matter that fuels the base of the food web) from both within the Bay and from external sources (many of which are low quality and require biochemical digestion via bacteria to generate food). External sources include organic material in freshwater inflows from rivers, wastewater discharges and fringing marshes. How important is this external subsidy? Based on an average estuarine total organic carbon level (C) of 2 milligrams per liter, a 20 MAF/yr flow supplies an average annual load of about 100,000 tons of carbon to the Bay per year, or about 80 gC/m^2/yr Baywide (grams of carbon per square meter per year). This is substantial compared to within-Bay food production (estimated Baywide phytoplankton production is 150 gC/m^2/yr, and bacterial production 90 gC/m^2/yr). There are several limits to the use of this production: First, only a small fraction (10-30%) of the DOM/POM is readily available to support the rapid growth of bacteria; second, to produce one unit of biomass bacteria need about three times as much carbon (thus the Baywide average bacterial carbon demand is about 270 gC/m^2/yr). In general, bacterial production in S.F. Bay appears to be limited by the availability of organic matter and is at the low end of the range for other estuaries and coastal waters (Hollibaugh, SOE, 1996). (See also Hollibaugh, Lehman, p. 54.)

Bacterioplankton Production in SF Bay
Compared with other coastal and estuarine ecosystems, mg C/m^3/d



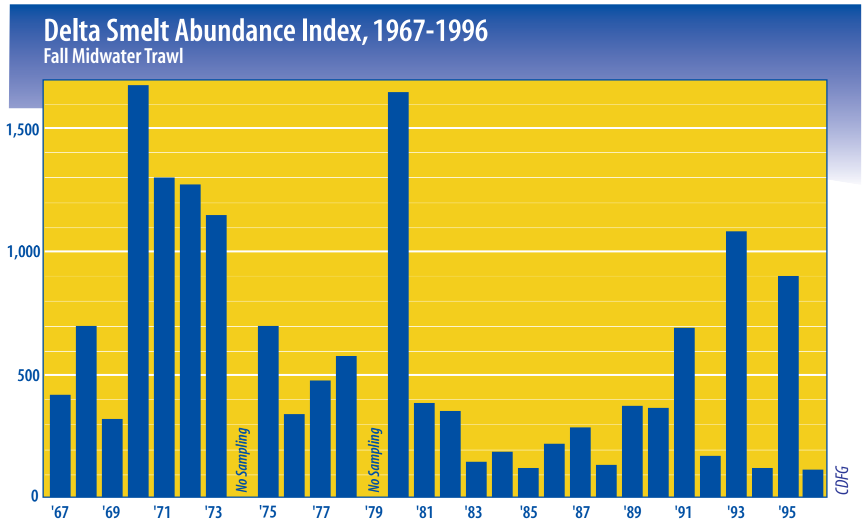
Ecosystem number corresponds to the sequence in this table: 1-4 are salt marshes; 5-20 are estuaries; and 21-45 are coastal waters. S.F. Bay data (from Table 1 in Hollibaugh and Wong 1996) are presented for the following reaches: Rio Vista to Martinez (Ecosystem 47); Vallejo to Bay Bridge (Ecosystem 48); and Hunter's Point to Dumbarton Bridge (Ecosystem 49). The extreme range of the South Bay data set reflects the influence of the spring phytoplankton bloom. (Data for other areas taken from Ducklow and Carlson 1992).

LONGFIN SMELT

Longfin smelt abundance in the Estuary reached an all-time low in 1992 (fall-midwater trawl survey index=73) following 6 years of drought. This 4-5-inch-long (adult), pelagic anadromous species spawns in the fresh waters of the Delta and lower rivers, rears throughout the Estuary and matures in brackish and marine waters. There is a strong relationship between freshwater outflow during the spawning and larval periods and the subsequent abundance of longfin smelt (see graph p. 4). Outflow disperses buoyant larvae — increasing the likelihood that some will find food. By reducing salinities in Suisun and San Pablo bays, outflow may also provide habitat with few marine or freshwater competitors and predators (marine species often do not tolerate lower salinities, and freshwater species have mechanisms to avoid being washed downstream). Moderate outflow in 1993 resulted in a modest population rebound (abundance index=797). In 1994, some early spawning (at age 1) of the 1993 year class augmented the 1992 year class spawning so that the fall index was moderate for a low outflow year (index=523). Both the 1993 (age 1, returning to spawn) and 1994 (age 0-1, rearing in the Estuary) year classes contributed to the 1994 index. In 1995, sufficient spawning stock and high outflow led to very good survival (age 0-1) and returned the population to pre-drought abundance levels (index=8,632). A smaller spawning stock and moderately high outflow in 1996 resulted in a substantial increase in abundance above the parent stock, but did not quite reach pre-drought levels (index=1,356). Stock size and water conditions in 1997 appear sufficient to produce another large jump in population (Baxter, SOE, 1996).

DELTA SMELT

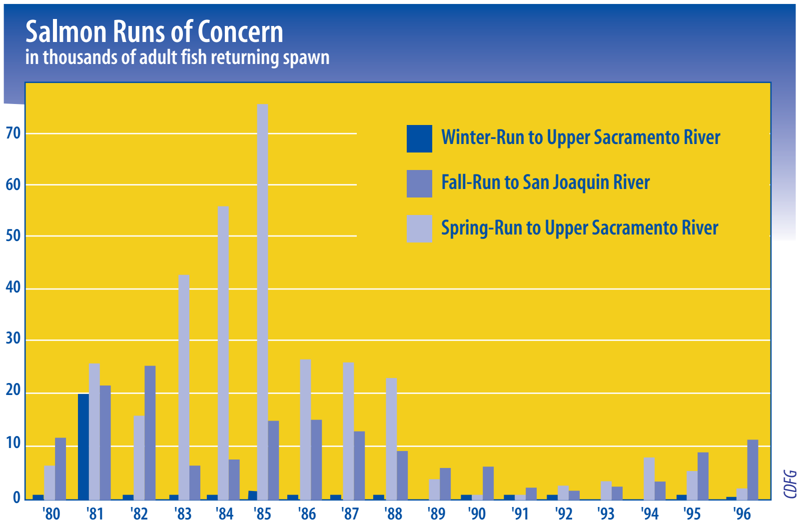
The Delta smelt — listed as a federal and state threatened species in 1993 — is a 2-3-inch-long (adult), slender-bodied fish. Though historically one of the most common species in the Estuary, the population declined dramatically in the early 1980s. Delta smelt are considered environmentally sensitive because they only live one year, have a limited diet and reside primarily in the interface between salt and fresh water. Possible reasons for their decline include reductions in outflow and extremely high outflows (pushing them too far down the Estuary), entrainment losses to water diversions, changes in food organisms, toxic substances, disease, competition, predation and loss of genetic integrity. More recently, Delta smelt abundance increased in 1993 to the sixth-highest index (1079) in a 28-year record, an apparent response to an increase in available habitat brought about by a wet winter and spring, which ended the seven-year drought. In 1994, however, the population reached its lowest point (101) in a 26-year record, probably due to high summer mortality. Abundance rose again in 1995 to the seventh-highest index on record (899), despite extremely high winter outflows through May. In 1996, good spring habitat conditions in Suisun Bay should have led to good survival of eggs and larvae; however, by the fall, the population was once again declining (126). Delta smelt may do better when river outflow is allowed to flow downstream and create nursery habitat in Suisun Bay — a flow-management approach adopted by state and federal pump managers in late1994 (see p. 23) (Sweetnam, SOE, 1996).



SPLITTAIL

Young of the year (age 0-1) splittail abundance in the Estuary was poor through most of the drought (index =1-15), but improved substantially in 1995 (index=75), when good outflow conditions led to a very large year class. The abundance of this 13-15-inch minnow is positively related to freshwater outflow during its spawning and larval periods (March-May). In 1996, though outflow was relatively high, young-of-the-year abundance was similar to the highest index during the drought (index=11). In 1997, peak outflow occurred before the typical splittail spawning season, but water temperatures were warm enough to induce early spawning, and flows may have persisted long enough for good egg and larval survival. During the high flows of winter and spring, this species migrates from summer and fall range in tidal, fresh and brackish water into fresh water to forage and spawn. Some ascend the Sacramento and San Joaquin rivers for more than 100 miles before spawning. Others spawn in the flooded areas in and adjacent to the Delta, like the lower Cosumnes River. A large segment of the population appears to forage and spawn in the flooded farm-fields and terrestrial habitat of the Sutter and Yolo bypasses. Such floodplains, with their abundant drowned invertebrates, may improve nutrition, leading to better fertility, and may also provide superior incubation and nursery grounds. About a month of flooding during the spring spawning period is necessary for incubation, growth and successful larval emigration from floodplains. Many larval and early juvenile splittail are transported to the Delta by freshwater outflow (Baxter, SOE, 1996).

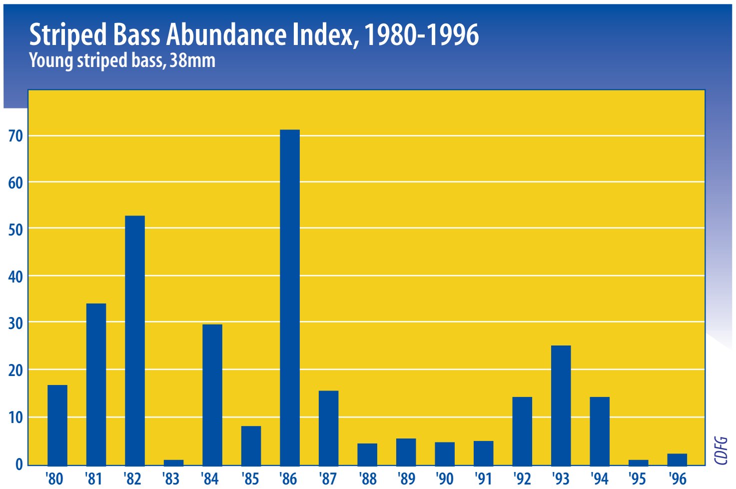
CENTRAL VALLEY SALMON



Chinook salmon populations in the Central Valley continue to exhibit long-term declines, with recent improvements in some areas due to better inland and ocean habitat conditions. Central Valley salmon occur in four discrete runs in the Sacramento River system — winter-run, spring-run, fall-run and late fall-run (run refers to the season in which adults return from the ocean to spawn). Of all these stocks, the winter-run Chinook has the lowest population and is listed as both a state and federal endangered species. The returns of 1,361 winter-run in 1995 and 900 in 1996 were a significant increase over the 1994 all-time low of 189 fish. The next-most-sensitive stock is the spring-run Chinook, currently under consideration for state listing as a threatened species. Spring-run abundance averaged 13,000 during 1967-1991, however, recent populations in several remaining Sacramento River tributaries (Deer, Mill and Butte creeks) are at low levels. No population-trend data for late fall-run Chinook salmon are available since 1994, when operational changes at the Red Bluff dam began precluding counts during the upstream migration period. Late fall-run abundance, however, averaged 14,000 during 1967-1991. Sacramento fall-run Chinook remain the most abundant and ubiquitous Chinook stock, and the 1996 return of 212,000 was a significant increase over the previous six years. San Joaquin fall-run Chinook returns in 1996 remained far below the 1967-1991 average annual return of 21,000 (Mills, SOE, 1996). (See p. 17 for a survey of salmon in Bay Area streams.)

STRIPED BASS

Striped bass, a species important to recreational fishing, continues a major decline dating back to 1977. In 1996, the abundance index of young 38-mm bass was 2.1 — the lowest recorded since the summer tow-net survey began in 1959 (for comparison, the record high index was 117.2 in 1965). The fall-midwater trawl survey also yielded the lowest index on record. Such low indices are unusual for wet years. Working theories of why the striped bass has declined over the long term include young fish entrainment (loss) at the water export pumps and subsequent lower recruitment to the adult population and resulting egg production; greater migration of adult bass out to sea with El Niño events; and reduced "carrying capacity" of the system. Population estimates for legal-sized fish (for sport catch) were about 1.8 million in the early 1970s and are now about 0.6 million. The small water-management changes made to benefit bass in the late 1970s have been insufficient to curb the trend, and it is unlikely that any further changes are possible given the human population increase and consequent water needs in California. Hence the resumption of hatchery stocking, currently curtailed until impacts on endangered species are evaluated, may be the only feasible way to sustain the population for continued sport fishing (Miller, Pers. Comm.).



COMMERCIAL FISHERIES

The spawning biomass of Pacific herring — which support the Bay's largest remaining commercial fishery — was the third highest on record in 1996-1997, at 89,000 tons. The previous year produced the second-highest biomass on record, at 99,000 tons, while just a few years before (1993) yielded the lowest on record. In general, the population seems to be on the rebound after declines during the recent drought. However, abundance of young-of-the-year (YOY) was unexpectedly low in 1996 (Hieb, Pers. Comm.). In the past, YOY abundance has been high in years such as 1996 (high outflow and high broodstock abundance), but too much outflow may have a negative impact. For example, heavy rains in early 1997 added so much fresh water to the Bay that the herring held off spawning through most of January (Watters, Pers.Comm.). The impact of the late spawn is not known, but salinity continues to have a major impact on the reproductive success of this species. The ideal salinity for egg fertilization and embryonic development is between 12 and 20 parts per thousand (ppt). Hatching rates decrease at salinities below 8 ppt, while the number of abnormal larvae increase at above 24 ppt (Griffin 1997 and Vines 1996). To maintain a viable fishery, Cal Fish & Game sets and adjusts herring quotas every year (herring abundance fluctuates widely whether fished or not). The Bay-Delta region sustains several much smaller commercial fishing operations: bait fisheries (Bay shrimp, shiner perch, midshipman, mudsuckers, bullhead, threadfin shad and a freshwater clam); a brine shrimp fishery in salt ponds; a small "hook-and-line" fishery for halibut, white croaker, rockfish and surfperch; and a crayfish fishery.

NATIVE FISHES IN BAY STREAMS

At least 75% of fish species native to Bay creeks are maintaining healthy populations. A 1994-1997 survey of 30 local watersheds (and 300 sampling sites) collected 16 native fish species (as compared to 27 recorded historically). Of 17 fishes endemic to the Sacramento-San Joaquin drainage, 11 (65%) were recorded in Estuary streams. Portions of many watersheds contain fish assemblages dominated by native fishes, as measured by the number of species and individual species abundances. In several watersheds native fish assemblages of 6-10 species remain intact, while exotic fishes are uncommon or absent. Examples include Sonoma Creek, the Napa River, upper Coyote and Alameda creeks and their tributary streams. The following is a summary of fish findings from the survey (Leidy, 1997).

U.S. EPA Biologist Rob Leidy surveys Bay creeks.

Lampreys — Bay streams once sustained at least three species of lamprey. The Pacific lamprey (*Lampetra tridentata*) is probably more common than historical records indicate and occurs today in lower Coyote Creek, Alameda Creek, Sonoma Creek and the Napa River, as well as in two of its tributaries — Chiles and Conn creeks. The status of the river lamprey (*L. ayresii*) within California is poorly documented, and the species is currently on Cal Fish & Game's "Watch List." A single specimen was collected during this survey (see above) in a tidally influenced reach of the lower Napa River. A third lamprey species, the western brook lamprey (*L. pacifica*), was last recorded in study area streams in 1924.

Trout — Rainbow trout/steelhead occurred at 41% of the sampling sites in the survey (the two fish are genetically almost indistinguishable, but the steelhead, unlike the rainbow, migrates out to sea). Steelhead (*Oncorhynchus mykiss irideus*) were recently listed as threatened along the central California coast. Most Estuary streams with suitable habitat probably once supported steelhead below natural migration barriers such as waterfalls. Most collections in this survey probably represent resident rainbow trout (*Oncorhynchus mykiss mykiss*). However it is difficult to differentiate between juvenile resident rainbow trout and steelhead where populations exist below migration barriers such as dams. Rainbow trout are known to migrate out of several reservoirs into Estuary streams to spawn. These fish are most likely "landlocked" or residual steelhead. Currently, small steelhead runs exist in the South Bay in San Francisquito Creek, the Guadalupe River, and Coyote and Permanente creeks; in the East Bay, possibly in Alameda and San Lorenzo creeks; in the Central Bay in Corte Madera, Miller, Arroya Corte Madera Del Presidio and Novato creeks; and in the North Bay in the Napa River drainage, the Petaluma River and Sonoma Creek. Tributaries to Suisun Bay that support steelhead runs include the Sacramento and San Joaquin rivers, and Green Valley, Suisun and Walnut creeks. Steelhead adults and juveniles may be found foraging in and migrating through estuarine subtidal and riverine tidal habitats within all areas of the Estuary.

Salmon — Small spawning runs of Chinook salmon (*Oncorhynchus tshawytscha*) occur in the Guadalupe River (several hundred spawners), Coyote Creek, Walnut Creek, Sonoma Creek and the Napa River, but the abundance of Chinook in these drainages is poorly documented. The federally threatened Coho salmon (*O. kisutch*) was historically present in several of the region's streams but none were found during this survey.

Minnows — Six of the eight known minnow species endemic to the Sacramento-San Joaquin River systems were found in the survey. Only the thicktail chub (*Gila crassicauda*), historically from Coyote Creek, Santa Clara County, is now extinct. Also not found in this survey was the speckled dace (*Rhinichthys osculus*) but the species may persist in remote reaches of the Alameda Creek system. The most common minnow collected was the California roach (*Hesperoleucus symmetricus*), occurring in 43% of the sites sampled. The closely related hitch (*Lavinia exilicauda*) occurred at 6% of the sites, down from 11% in 1981. The predaceous Sacramento squawfish (*Ptychocheilus grandis*) occurred in 13% of the samples, typically in the clear, shallow pools of larger perennial streams. Of particular interest is the isolated population of hardhead (*Mylopharodon conocephalus*) confined to the middle reaches of the Napa River — the only documented record of this species outside of the Central Valley, with the exception of the Russian River drainage. The hardhead is currently on Cal Fish & Game's "Watch List." Splittail (*Pogonichthys macrolepidotus*) — currently under consideration for listing as endangered or threatened — was found in the Petaluma River above Petaluma and is known to occur near the mouth of the Napa River and Walnut Creek. Sacramento blackfish (*Orthodon microlepidotus*) occurred in less than 1% of the samples.

Sculpins — Prickly sculpin (*Cottus asper*) and riffle sculpin (*C. gulosus*) were recorded at 27% and 7 % of the sampling sites, respectively. Prickly sculpin occurred in habitats ranging from turbid pools in highly disturbed, channelized stream sections to clear headwater streams between the elevations of 1m and 400m. In contrast, riffle sculpin preferred heavily shaded, undisturbed middle to headwater reaches of streams with low turbidity and sand and gravel substrates.

Status of Native Fishes
In streams of the San Francisco Estuary

SPECIES	STATUS[a]
PETROMYZONTIDAE	
Pacific lamprey, Lampetra tridentata	R?
River lamprey, L. ayresi	R?
Pacific brook lamprey, L. pacifica	0, R?
ACIPENSERIDAE	
Green sturgeon, Acipenser medirostris	0, S
OSMERIDAE	
Delta smelt, Hypomesus transpacificus	0, R
SALMONIDAE	
Coho salmon, Oncorhynchus kisutch	0, EX?
Chinook salmon, O. tshawytscha	R
Chum salmon, O. keta	0, S
Steelhead trout, O. mykiss irideus	R, D
Resident rainbow trout, O. mykiss mykiss	C
CYPRINIDAE	
Hardhead, Mylopharadon conocephalus	R
Splittail, Pogonichthys macrolepidotus	0, D
Thicktail chub, Gila crassicauda	0, EX
Hitch, Lavinia exilcauda	LC, D
California roach, Lavinia symmetricus	C
Speckled dace, Rhinichthys osculus	0, EX?
Sacramento blackfish, Mylopharodon conocephalus	LC
Sacramento squawfish, Ptychocheilus grandis	LC
CATOSTOMIDAE	
Sacramento sucker, Catostomus occidentalis	C
GASTEROSTEIDAE	
Threespine stickleback, Gasterosteus aculeatus	C
COTTIDAE	
Prickly sculpin, Cottus asper	C
Riffle sculpin, C. gulosus	LC
Coastrange sculpin, C. aleuticus	0, R
Pacific staghorn sculpin, Leptocottus armatus	LC
CENTRARCHIDAE	
Sacramento perch, Archoplites interruptus	0, R
EMBIOTOCIDAE	
Tule perch, Hysterocarpus traskii	LC
GOBIIDE	
Tidewater goby, Eucyclogobius newberryi	0, EX
Longjaw mudsucker, Gillichthys mirabilis	LC

[a]Status within the drainage is abbreviated as follows: EX = extinct; R = rare; D = depleted and declining, range and numbers substantially reduced; C = common throughout range; LC = locally common; S= stray; 0 = not collected during this study; ? = current status unknown.

Leidy

Sunfish — Sacramento perch (*Archoplites interruptus*) persist in the Alameda Creek drainage in abandoned gravel pit ponds once connected to the creek and within Calaveras Reservoir, though historically they occurred in three Estuary drainages. Fish and game agencies stocked the perch in various reservoirs throughout the Western United States. In the Bay Area, the Alameda population may represent the only remaining strain derived from native stream populations. Cal Fish & Game has listed this species as of "Special Concern" (Moyle et al. 1995).

Surfperch — Tule perch (*Hysterocarpus traskii*) — never widespread within the Estuary's smaller streams — persist in abandoned gravel pits adjacent to Alameda Creek and in the lower reaches and tidal marshes and sloughs of the Napa River and Sonoma Creek, as well as in various locations in the Delta (Leidy 1997).

Healthy Streams
In the San Francisco Estuary

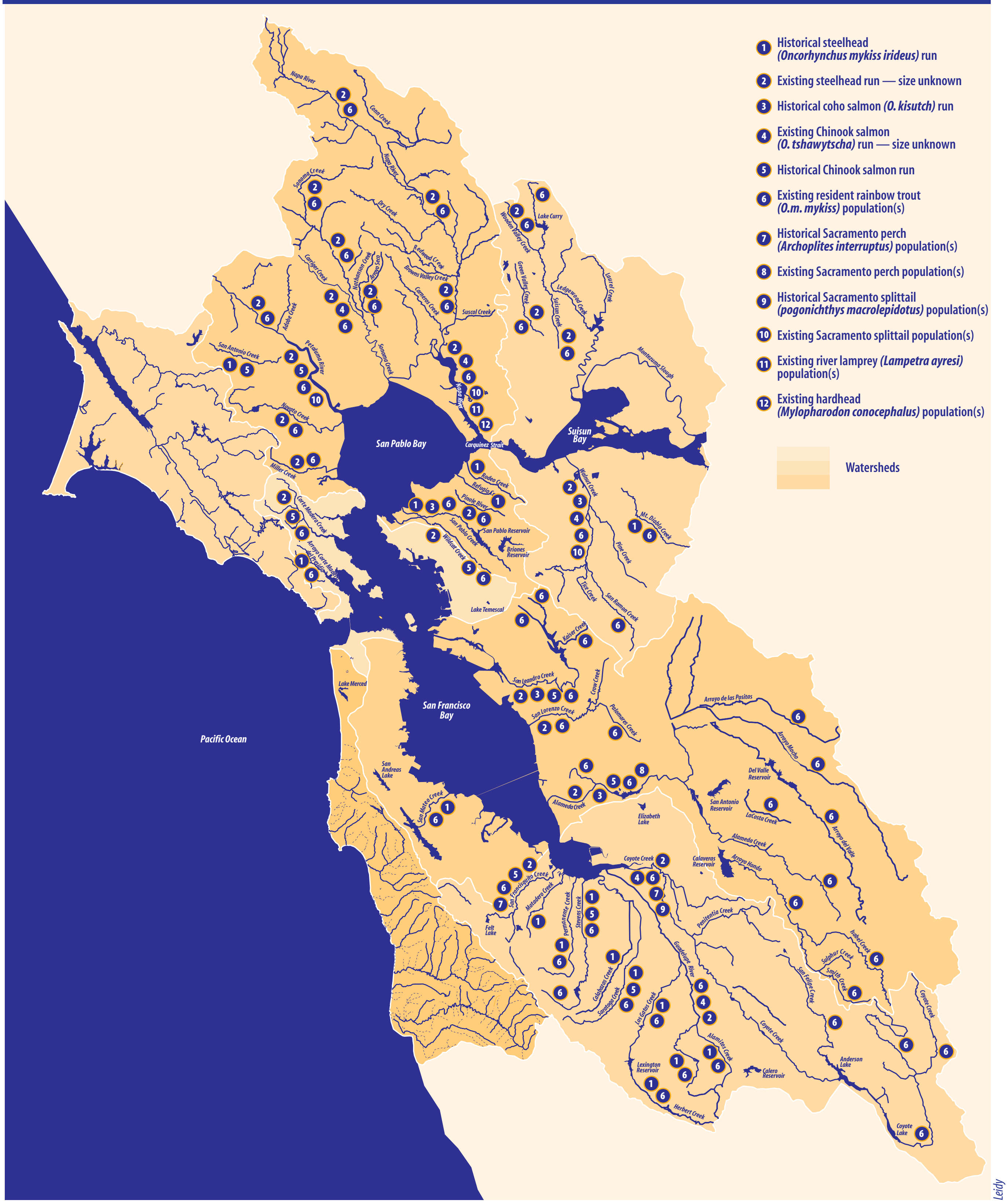
WATERSHED/LOCATION	HIGH SCORERS IN ECOLOGICAL INTEGRITY
Alameda Creek	Alameda Creek, Niles Canyon
Alameda and Santa Clara Counties	Alameda Creek, upstream from Sunol
	San Antonio Creek and tributaries, upstream from San Antonio Reservoir
	Arroyo Hondo Creek and tributaries, upstream from Calaveras Reservoir
	Arroyo Mocho Creek, upstream from Livermore
	Del Valle Creek, upstream from Del Valle Reservoir
San Leandro Creek, Alameda and Contra Costa Counties	San Leandro and Redwood creeks, upstream from Upper San Leandro Reservoir
Mt. Diablo Creek, Contra Costa County	Within Mt. Diablo State Park
Permanente Creek, Santa Clara County	Entire
Coyote Creek watershed, Santa Clara County	Coyote Creek and tributaries, upstream from Coyote Reservoir
Guadalupe River watershed, Santa Clara County	Entire
Saratoga Creek, Santa Clara County	Entire
Stevens Creek, Santa Clara County	Upstream of Stevens Creek Reservoir
San Francisquito Creek, Santa Clara and San Mateo Counties	Entire
San Mateo Creek, San Mateo County	Upstream from Crystal Springs Reservoir
Corte Madera Creek, Marin County	Entire
Miller Creek, Marin County	Entire
Petaluma River, Sonoma County	Entire
Sonoma Creek watershed, Sonoma County	Entire
Huichica Creek watershed, Sonoma County	Entire
Napa River watershed, Napa County	Entire
Green Valley Creek, Solano County	Entire
Suisun Creek, Solano County	Entire

Leidy

BIODIVERSITY IN BAY STREAMS

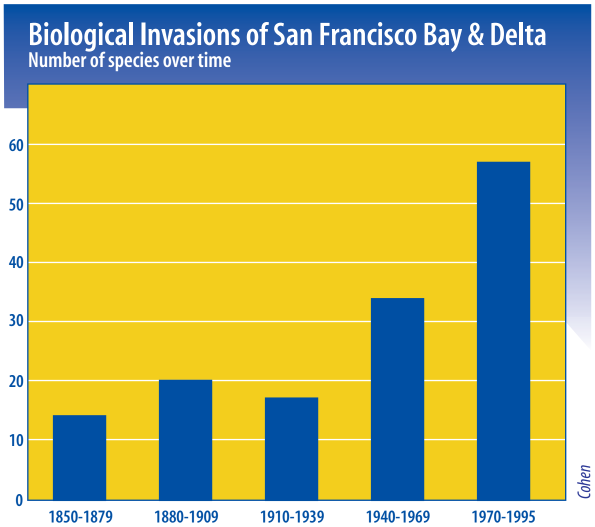
A survey (see "Native Fishes" above) of 30 watersheds found 20 stream segments with high ecological integrity or unique resources making them worthy of being put on the priority protection list (see "Healthy Streams" table). A comparison between 1984 and 1994 -1997 conditions suggests there's been a slowing and, in some drainages, a reversal of degradation over the last decade. The survey measured 11-15 biotic and physical factors to arrive at a functional index of the health of individual stream reaches and watersheds. Factors rated included such things as the diversity and abundance of native fishes and amphibians (see above); hydrological processes (such as the presence of natural flood and drought flows); and habitat conditions, arrangement and connectivity. Results indicate that Bay streams offer significant repositories of aquatic biodiversity in a state where only 23% of the native freshwater fauna can be regarded as secure. Of the 116 fish taxa native to the state, 7% are extinct, 13% are formally listed as threatened or endangered, 23% qualify for such listing, and 19% may qualify in the near future (Leidy and Moyle 1997). With urbanization and growth based on county general plans, at least 28,000 acres of the 12-county Bay-Delta region's 380,000 acres of stream environment have been eliminated or adversely impacted since 1992, or will be in the near future. Of 111 local governments in the region, only 18 had specific ordinances to protect wetlands or creeks as of 1992 (no more recent information available) (SFEP 1992).

Distribution of Native Fish in Bay Creeks



BIOINVASION RATES

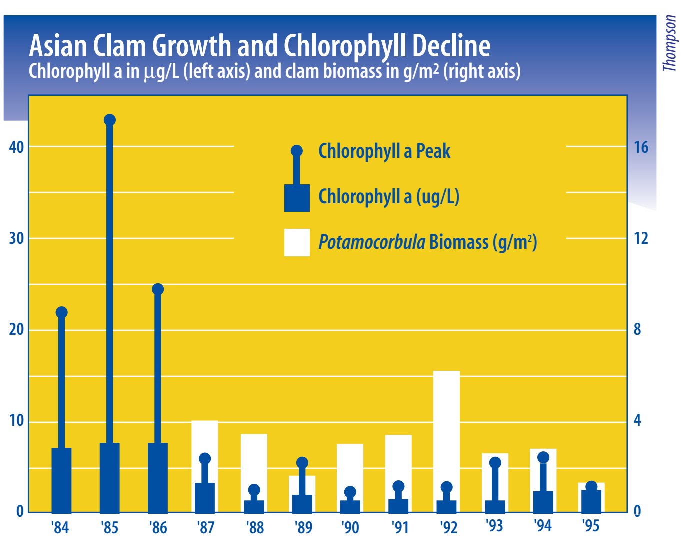
At least 212 non-native organisms have established themselves in the Estuary's waters and wetlands to date. Such invasions — many of which occur via the discharge of ship ballast water taken up in foreign ports — may constitute the biggest single threat to the Estuary's native biodiversity. More significant than the sheer number of exotics is their dominance in many aquatic communities. In several studies since the 1940s, exotic species accounted for 40-100% of the common species and up to 95% of the biomass of several biotic assemblages, including soft-bottom benthic organisms, dock- and hull-fouling organisms, zooplankton in the northern part of the Estuary and fish in the Delta. Moreover, the rate of invasions has been increasing: Between 1850 and 1970, an average of one new species became established in the Estuary every 46 weeks; since 1970, the rate has jumped to one new species every 15 weeks. Some of these invasions have greatly altered habitat structure and the flows of nutrients and contaminants, and, through predation, competition and the introduction of parasites, have contributed to reductions and extinctions of native species. The economic costs of exotic species include damaged marine facilities, weed-choked waterways, fouled water intakes and undermined river and ditch banks (Cohen, SOE, 1996).



Biological Invasions of San Francisco Bay & Delta
Number of species over time

CLAM TRENDS

Since the non-native clam *Potamocorbula amurensis* arrived in S.F. Bay, it has changed the benthic community, planktonic community and contaminant transfer in North Bay. Changes to the benthic community include the replacement of other bivalve species; a shift in the community structure, with bivalves now comprising close to 100% of the benthic community's biomass in some locations; and an apparent increase in the stability of the number of species in the community (fewer natural fluctuations in the diversity of species). The circumstantial evidence that *P. amurensis* overgrazes and decimates the phytoplankton in Suisun Bay has been strengthened by recent data. Despite increased freshwater flows in 1993 and 1995, the phytoplankton biomass (measured as chlorophyll a) remained low while the *P. amurensis* biomass, although lower, remained high enough to maintain the low phytoplankton standing stock. Conservative estimates of grazing rates show this clam population is capable of filtering the water column at least 1-2 times a day in the shallow reaches of the Bay. The population receives 1/8-1/2 of its food from locally grown phytoplankton and is thus consuming other sources of carbon which may now be less available to other members of the food web. In addition, the transfer of contaminants from the benthos to other members of the food web has changed, as this clam bioaccumulates trace elements differently from previous benthic residents (see p.43). *Potamocorbula amurensis* is now considered a permanent member of the benthic community (Thompson, SOE, 1996).



Asian Clam Growth and Chlorophyll Decline
Chlorophyll a in µg/L (left axis) and clam biomass in g/m² (right axis)

ZOOPLANKTON CHANGES

Many of the zooplankton species in the northern reach of the Estuary now consist of introduced species. Since 1987, native species have declined in abundance, and their spatial and temporal ranges have shrunk. In some cases, the causes of this decline are clear: For example, several small crustaceans including copepods and mysid shrimp declined sharply in abundance and range following the spread of the clam *Potamocorbula* (see above).

Some of these declines were due to consumption of young stages of copepods by the clam, and others (particularly with regard to mysid shrimp) due to competition with the clam for food. Declines were substantial, up to 90% for some species. At the same time, however, several species of zooplankton with similar characteristics to the native species are thriving. It is still unclear how these species survive the effects of the clam and whether they are suppressing the recovery of native species through competition (Orsi & Kimmerer, SOE, 1996). (See also Sloan p. 55.)

FISH INVASIONS

Since Gold Rush times, 18 fish species have successfully invaded the Estuary, and more invasions seem inevitable. These introduced fish species occur mainly in fresh and brackish water, where they often dominate in terms of numbers and/or biomass. A certain amount of integration has taken place among the native and introduced species, resulting in new assemblages that seem to respond in concert to estuarine conditions. Invading species have also likely contributed to the decline of native species, not to mention increasing uncertainty about the effectiveness of management measures designed to enhance populations of declining native species (because it is hard to separate the effects of a new invasion from changes to the environment). Inland silversides, for example, may be partially responsible for the Delta smelt decline because they prey on smelt eggs and larvae, while wakasagi may make smelt recovery more difficult because this invader hybridizes with and may compete with the smelt. Some invaders, such as the shimofuri goby, appear to have had no major effects on the native biota but could invade estuaries elsewhere via the California aqueduct and then compete with and prey on the endangered tidewater goby. Two fishes likely to invade the Estuary in the near future are the northern pike and white bass (established due to illegal introductions for sport fishing). As top predators, they are more likely to cause significant ecological change and greatly alter current fish communities. With today's increased knowledge of introduction pathways, all future invasions must be regarded as preventable and therefore the responsibility of those making the introduction (Moyle, SOE, 1996).

MITTEN AND GREEN CRABS

The invading Chinese mitten crab (*Eriocheir sinensis*) — responsible for millions of dollars in damage in Europe — was first collected in South San Francisco Bay in 1992 and has since steadily increased in abundance and distribution. Crabs were collected in San Pablo Bay in the fall of 1994, Suisun Marsh in February 1996 and the Delta in August 1996. Its distribution in South Bay creeks also continued to expand in 1996, with mitten crabs reported approximately 30 miles upstream from the mouth of Coyote Creek and in the Niles Canyon section of Alameda Creek. In the South Bay, mitten crab burrows are common in tidally influenced areas with steep banks that are high in clay content and lined with vegetation. Burrow densities as high as 30 per square meter have been reported from South Bay sloughs. In other areas, mitten crab burrowing has accelerated bank erosion rates and slumping. As their population grows in the Delta and other parts of the Estuary watershed, the crab's burrowing activity could pose a serious threat to the structural integrity of the levees.

Lee Mecum

Another crab invader, the green crab (*Carcinus maenas*), is native to the Atlantic coast of Europe and was first collected from Redwood Shores Lagoon in South San Francisco Bay in either 1989 or 1990. Its distribution in the Estuary expanded rapidly, and by 1994, green crabs were collected throughout the lower Estuary, from the South Bay to the Carquinez Strait. In 1995 and 1996, years with high outflow, densities were highest in the South Bay, and crabs were not distributed as far upstream as in 1994. Green crab distribution in the Estuary is limited by salinity; crabs have been collected from 7.5-31 ppt (salt to water) with few from less than 10 ppt. The green crab primarily inhabits intertidal and shallow subtidal areas and is a well-documented predator of bivalves, polychaetes and small crustaceans. Competition for food resources may impact shorebirds and other intertidal or shallow subtidal predators, such as the Dungeness crab (Cohen et al. 1995; Grosholz and Ruiz 1995). The green crab may also compete with juvenile Dungeness crabs for space. In laboratory and field enclosure experiments, green crabs have consumed smaller and equal-sized Dungeness crabs (Grosholz, Pers. Comm.). A large green crab population in the Estuary could decimate a Dungeness crab year class (Hieb & Halat, SOE, 1996).

SCIENTIFIC PERSPECTIVE

WHAT WE'VE LEARNED ABOUT FISH AND THE AQUATIC ECOSYSTEM

DR. RANDALL BROWN
Chief Scientist
California Department of Water Resources

Transcript of Summary of State of the Estuary Conference Flows Presentations

"The Estuary is constantly changing; that's what estuaries do. Flows change, new critters come in and people change the system themselves. At the moment, we continue to get a large number of non-native animals and plants coming into this Estuary. We don't always want those animals and plants — they can be nuisances. We have shown that on the bottom of the Bay, most of the critters are introduced. This Estuary has been termed the most invaded estuary in the world. There's federal, state and even international legislation in place now to help prevent ballast introductions by having the ships discharge their ballast water in the open seas. But this is a voluntary, and as yet not mandatory, program.

"There's an animal coming this way called the zebra mussel; it's in the Great Lakes in the Midwest, where they're spending about $30 million per year to control it. It has completely clogged pipes. We have found ten of these animals on boat hulls at the border checkpoints coming into California, and four were alive. If we've caught ten of them, probably more are coming. So, introduced species are a major problem in the Estuary. What we have today isn't what we had yesterday or what we'll have tomorrow because they keep coming.

"Moving from invasions to the food chain, we've learned that contrary to earlier expectations, most of the food consumed in Suisun Bay actually comes from nearby rivers, marshes and tidelands. It's not grown in the Bay. So the phytoplankton component isn't the driving force in that food web, a fairly startling revelation.

"Back to invasions, many zooplankton (the small animals that are food for the small fish) we had in the system are changing too. The ones we used to have aren't often the dominant ones that we have nowadays. We're not sure if the changes have replaced the food that was available through the earlier animals or have changed the food web in a way that will affect the fish populations.

"Two new crabs were introduced into the system during the last ten years. The European green crab is in the Bay itself, and the mitten crab from China spawns in saltwater and moves up into the fresh water. Juveniles and adults can go several hundred kilometers in the fresh water, even over dams. The mitten crab loves rice shoots and burrows into levees, so it's probably of some concern to people in the Valley. In Germany several years ago, they had so many you couldn't walk outside at night without stepping on them.

*"The Asian clam (*Potamocorbula*) came in about 1986. This animal seems to have really depleted the phytoplankton crop, or what there was of it in Suisun Bay. So the blooms we used to have are no longer there. It also appears to be eating some of the younger stages of zooplankton. So the clam is changing the dynamics of the Estuary. It survived several recent high-flow years despite our hopes that it might be washed out.*

"We've also had lots of fish invasions. In the northern Estuary — Suisun Bay and the Delta — most of the fish that we see are introduced. Catfish, black bass, gobies and striped bass are all introductions, and most of them on purpose. In the Bay itself, most of the fish are natives. Northern pike eat other fish. Some anglers wanted these fish in California, and so they probably brought in a bucket from Nevada and threw them in our reservoirs. They were eradicated in one reservoir, but people liked them enough to put them in another. We've got to keep northern pike out of the Estuary because they could hurt salmon and other native fish.

"Now, for the native fishes. They've been up and down as happens to fish in estuaries. We have a splittail which has been proposed for listing. During the long drought (1987-1992), juvenile splittail abundance declined quite a bit. But in 1995, a big water year, we saw hundreds of millions of splittail, which had reportedly been extirpated from the San Joaquin drainage, come out of that system. The flow-splittail relationship held. But what we're seeing now is that although there may still be a relationship between outflow and fish abundance for many species, for given outflows, we're often getting less fish now than we used to.

"Longfin smelt had the same kind of relationship with flow. Populations got very low in the late 80s. It was proposed for listing, but Fish & Wildlife declined to list because longfin smelt are found in estuaries up and down the West Coast. Last year was a pretty good year for longfin smelt. They came back with the high flows.

"Delta smelt — We've had pretty good years since 1990. Between 1982 and 1990, the abundance was quite low. This year, it appears the fall abundance is going to be low again. We have spent about $3.5 million studying them because we don't know much about Delta smelt. There's no relation between flow and Delta smelt abundance — a big puzzle for us.

"Chinook salmon — The winter-run is now listed as endangered. Another race, the spring-run, is petitioned and may be listed soon. The late fall-run is probably declining. The fall-run is quite abundant, but it's mainly hatchery-supported. Last year, we had a very good run of fish into the Valley — one of the best ones we've had in a long time. Ocean conditions could have been the source of the good fishery and good escapement.

"So overall we had some bad years in the 1980s during the drought periods. But since 1990, we've had a pretty good recovery. The one fish that hasn't come back is striped bass; abundance has not rebounded even with good flows. But things are looking better from the standpoint of the management of the system with everybody now working together toward restoration and recovery."

Management Changes

BAY-DELTA ACCORD

The 1994 Bay-Delta Accord and the resulting state water-quality plan established new salinity-based flow standards beneficial to many fish and aquatic organisms. The new "estuarine habitat" standard adds more fresh water to the Delta in late winter and spring when Delta smelt and other native fish most need it. This standard requires adequate flows to maintain the 2 psu isohaline within a certain range of positions in the lower Estuary associated with abundance of some fish and biota (see pp. 4 and 9). Several other provisions in the Accord — in effect through December 1997 — benefit fish, including seasonal controls on the amount of pumping, restrictions on the take of endangered species, gate closures and a barrier to minimize fish losses at the pumps and San Joaquin River base flows and pulse flows during the fall-run salmon out-migration period. Wet weather has obviated the need for most of these actions in recent years. The Accord also created a federal-state "operations group" to make day-to-day decisions about pumping so as to minimize loss of endangered species. Such decisionmaking is aided by recently increased "real-time" (in-the-water) monitoring of fish movements and conditions in the Estuary. Lastly, the Accord established a special fund (Category III), which is now paying for 38 on-the-ground restoration projects.

Janet Delaney

Students from the Richmond High School Environmental Justice Project help monitor environmental conditions along nine-mile-long Wildcat Creek. In recent years, local groups, schools, scientists, and county and regional agencies have fostered numerous creek care projects along Wildcat, from keeping cows out of the streambed and tearing out concrete channels to recreating banks and monitoring water quality. These highschoolers have been examining, among other things, the temperature, turbidity, color and odor of the water — all of which affect fish habitat. As part of a related seafood consumption project, students are educating North Bay fishers and families about how to minimize their toxic intake through the proper cooking and cleaning of Bay-caught fish. This two-year-old environmental justice project — run by Friends of the S.F. Estuary and the S.F. Regional Board — received an award at the 1996 State of the Estuary Conference for its outstanding effort to implement the CCMP.

CVPIA ACTIONS

Habitat restoration actions to increase the Estuary's anadromous fish population (salmon, trout, bass, shad, sturgeon) have occurred since mandated by the 1992 Central Valley Project Improvement Act (CVPIA). Efforts have included the June 1997 release of a 176-action *Anadromous Fish Restoration Plan*, flow improvements for fish, construction of fish ladders and screens, development of watershed plans, fish monitoring, riparian land acquisition, channel restoration and planning for use of 800,000 acre-feet per year dedicated to fish under the act. Since 1992, use of this dedicated environmental water has been partial or incomplete each year as managers and users haggled over its accounting (such conflicts had not been resolved at press time). Recent wet conditions have eased user conflicts over fish-friendly flow management.

NATIVE FISHES RECOVERY PLAN

Scientists recently completed an ecosystem-based multi-species recovery plan for Delta fish. This *Delta Native Fishes Recovery Plan* covers seven species, including the endangered Delta smelt, the Sacramento splittail and two runs of Chinook salmon. Implementation is ongoing. Meanwhile, smelt take (loss) limits at the pumps have been exceeded several years in a row.

POTENTIAL NEW LISTINGS

Since 1992, fish and wildlife agencies have decided against listing one candidate for endangered species status: longfin smelt. While agencies turned down Sacramento spring-run Chinook salmon for listing earlier this decade, the state is now reconsidering. Splittail is still an active candidate. In 1997, the National Marine Fisheries Service listed steelhead trout as endangered on the southern California coast and threatened in the central California coast (including the Bay Area), providing a new regulatory framework for creek and watershed restoration and protection initiatives within the Estuary basin.

CALFED BAY-DELTA PROGRAM

CALFED's (see p. 9) fish-specific objectives include improving and increasing aquatic habitats so they can support the sustainable production and survival of native and other desirable estuarine and anadromous fish in the Estuary. Within CALFED's common program are several measures that will help fish, including improving and restoring shallow-water and riverine habitat, finding and acquiring more water for environmental use, controlling exotic species, installing more fish screens and continuing real-time monitoring of the location and health of fish populations. Each of CALFED's three basic storage and conveyance alternatives could have new or different negative impacts on fish as pump operations, flow patterns and water storage systems and management in the Estuary are modified (see p. 9). Such impacts will be mitigated as part of the program.

RIVER & CREEK RESTORATION

Enhancement of rivers and creeks can help provide essential upstream shade, food and habitat for fish. In the Delta, state flood protection programs have achieved no net loss in shaded riverine habitat since 1993. Meanwhile, a major new cooperative effort was recently launched to protect the Delta's estimated 800 channel islands, which include some of the only unfarmed or undeveloped biological remnants of early Delta riverine habitats. Upstream, at least 1,000 acres of riparian habitat have been restored on former agricultural land in the Sacramento River National Wildlife Refuge since 1993, and large-scale riparian restoration projects are ongoing along the Cosumnes (see p. 38) and American rivers, as well as downstream on the Bayshore at Tolay Creek. In the smaller creeks and drainages, numerous community and municipal creek awareness, cleanup, restoration and water quality monitoring programs are underway. In the Bay region, major recent creek restorations and watershed enhancement programs have improved environmental conditions for fish along San Leandro Creek, San Francisquito Creek, Alameda Creek, Corte Madera Creek, Sonoma Creek and the Napa River. A new statewide commitment to watershed management planning promises to further such improvements (see below).

Courtesy Fran Borcalli

The Maxwell Irrigation District is a leader in the recent wave of fish-screen construction to prevent water intakes and pumps from killing salmon and smelt in the Estuary watershed. Without any regulatory hammer over their heads, or any public dollars to ease the burden, the landowners of this 6,700-acre rice farming district near Colusa took out a $1.6 million bond to pay for a 100 cfs screen with an airburst cleaner at their intake on the Sacramento River in 1993. Officials say Maxwell's screen provided an invaluable functioning model of a screen built and paid for by farmers in a time when many water districts were stonewalling government efforts to get more screens. A year and a half and a new flow of public dollars for screen construction later, the district got some of its investment back from the government through CVPIA (there was no guarantee of this at the time of the screen's construction).

WATERSHED MANAGEMENT

State and federal regulators both adopted watershed management as a priority in the 1990s. Watershed management — in which all sources of pollution, erosion and habitat loss are considered within distinct hydrologic units — is now viewed as a sound step toward "ecosystem management." The State Board's 1995 *Watershed Management Initiative* now has regional boards working cooperatively with local interests to draft watershed management plans. In the Bay-Delta region, such planning efforts are progressing on a large scale for the Napa River, the Santa Clara Valley, the extreme South Bay and the Sacramento River basin, and on a smaller scale in many local watersheds. In 1996, diverse Bay-Delta interests agreed that among the S.F. Estuary Project CCMP's 145 actions, one of the top ten priorities should be preparing watershed management plans. Creek activists, meanwhile, see the new watershed management thrust as a long-missing driving force for creek and river restoration and for understanding the role of creeks in the health of the Bay, rivers and wetlands. A recent survey (see p. 18) of 30 Bay watersheds suggests that 20 stream segments or drainages contain aquatic or riparian resources unique or diverse enough to be worthy of consideration for special protection by local governments or regional restoration initiatives. The goal of the survey — carried out under the CCMP Action Plan for Aquatic Resources — was to identify potential "Aquatic Diversity Management Areas." To date, however, no specific agency or group has taken on the task of creating and implementing such "ADMAs." (See also Kondolf p. 57.)

EXOTIC SPECIES CONTROL

Nuisance species eradication programs are ongoing for northern pike in Lake Davis and several aquatic plant species, and border patrols now check for zebra mussels on boat hulls. On the regulatory and policy front, recent years have been marked by an increasing national and local commitment to ballast-water control in the prevention of aquatic species introductions. In 1997, the citizen watchdog group BayKeeper petitioned the S.F. and Central Valley Regional Boards to ban the discharge of ballast water in the Bay and Delta. Any such ban would make mandatory controls similar to those passed under the 1996 reauthorization of the National Invasive Species Act. The act established voluntary ballast water control guidelines for the nation and created a new western regional panel on invasive species.

3 WETLANDS & WILDLIFE

Jimmy Sculpa of Philip Williams & Associates measures the length and depth of an evolving tidal channel at the Sonoma Baylands wetland restoration site.

Overview

The wetlands and riparian zones along the Estuary's shores are some of the most ecologically and economically important components of the Bay-Delta system. They provide many benefits, including food-web support, habitat for fish and wildlife, flood protection, water-quality improvement and erosion control. They also provide waterfront open space and recreational opportunities.

Over 300 fish and wildlife species breed, raise young, feed and rest in Estuary wetlands. Over 60 plant and animal species in these wetlands are listed as rare, threatened or endangered, or are candidates for such listing. Hundreds of other species — particularly birds, amphibians, insects and freshwater fish — make their homes in the Estuary's riparian zones. Beaches and shoreline also offer important breeding sites for harbor seals and nesting spots for aquatic birds.

Courtesy Jay Plater, Foster and Associates

Endangered California Clapper Rail

Human development of the Estuary basin has resulted in the loss or conversion of more than 500,000 acres of tidal wetlands and thousands of acres of shoreline and stream habitat. In the Delta, 97% of the 345,000 acres of historic freshwater wetlands have been converted to other uses, mostly farms. In the Bay Area, 82% of the approximately 200,000 acres of historic tidal and brackish wetlands have been converted to other wetland types and to non-wetland uses. Development has also adversely affected non-tidal wetlands, particularly riparian forest and seasonal wetlands. Wetland loss has slowed substantially since the early 1970s, but continues.

The major human-induced threats to the Bay's remaining wetlands include highway and bridge construction, airport expansion and other shoreline development. Away from the immediate Bay margin, residential, commercial and industrial development (including associated flood control and transportation projects) threatens seasonal wetlands and riparian corridors. On rural lands, particularly in the counties experiencing high growth rates, wetlands face urban expansion pressure.

Although many of the Estuary's wetlands have been adversely affected by development, a sizable acreage is now protected in parks, refuges and preserves. In the Bay and Delta, more than 140,000 acres of wetlands are currently safeguarded by public and private entities (SFEP 1992, 1996). This represents about 22% of the Estuary's remaining wetlands.

Given the importance of wetlands and the extent to which they have been lost or modified, it is imperative that local, state and federal entities develop policies and programs to protect and enhance the Estuary's remaining wetlands and to increase wetland acreage and diversity throughout the region. They must also address some newer threats — the spread of invasive plants such as Atlantic cordgrass, shoreline erosion due to wave and boat action (resulting in the loss of up to 50 acres of tidal wetlands per year), poor implementation and follow-up on mitigation projects for wetlands lost to development and increasing conflicts between sensitive wetland species and shoreline visitors, not to mention introduced predators.

STATUS REPORT

CURRENT WETLAND ACREAGE

The Bay-Delta Estuary encompasses a total of 628,549 acres of wetlands. Over half of these (385,000 acres) are agricultural wetlands; the remainder include marshes, mudflats, streamsides, riparian woodland, salt ponds and other transitional areas between Estuary waters and the land (USFWS 1987). More up-to-date acreage measurements are now available for the lower Estuary. The Bay Area EcoAtlas documents current (1997) and historical (1800) wetland extents (see maps p. 34-35) — integrating data from many sources to provide a picture of different wetland habitats, as well as of watershed boundaries, infrastructure, land-use zoning and wildlife resources. The EcoAtlas, completed in summer 1997, offers a new tool for local and regional environmental planning and management.

RECENT ACQUISITIONS AND RESTORATION

Over 20,000 acres of Estuary wetlands have been acquired for the public trust since 1993. As of 1989, at least 66,440 acres of wetlands were permanently protected in the Bay region alone (SFEP 1992).

At least 8,137 acres of degraded or former wetlands have been restored and enhanced since 1993, and similar projects are planned or in progress on an additional 12,693 acres. Beyond these gains, another 12,442 acres with some kind of mitigation component (i.e., wetlands were lost nearby or elsewhere as part of the project) are being restored in the Bay and Delta, (SFEP 1996).

A crude comparison between two surveys spanning the last decade suggests a possible decline in tidal wetlands area in the Bay region, from 36,148 acres in 1987 (USFW) to 33,853 acres in 1997 (SFEI EcoAtlas). (Such a comparison offers only a guesstimate of the degree of change because measuring methods, wetland definitions and geographic scope may have varied between the two surveys.)

WETLAND EASEMENTS

At least 67,292 acres of wetlands are protected in the Central Valley and Suisun Marsh under perpetual conservation easements (federal, state and private) as of 1996 — almost double the 1989 easement acreage (SFEP 1996).

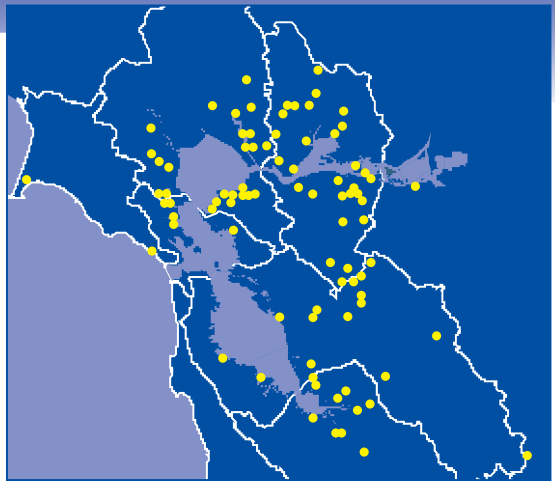
Acres of Bayland Habitats
Past & Present

	HISTORICAL 1770-1820	MODERN 1997
SUBTIDAL OR INTERTIDAL HABITATS		
Deep Bay (≥3 fathoms)	95,501	82,278
Shallow Bay (<3 fathoms)	167,801	167,696
Intertidal Bay Flat	48,835	28,520
Mature Tidal Marsh	190,559	16,773
Young Tidal Marsh	1,203	17,080
Muted Tidal Marsh	?	5,553
Lagoon	47	2,283
DIKED HABITATS		
Diked Marsh	possible native land use	9,002
Ruderal Bayland	"	2,834
Grazed Bayland	"	6,995
Farmed Bayland	"	25,349
Managed Bayland	"	50,586
Storage or Treatment Pond	"	4,700
Low Salinity Salt Pond	"	11,294
Medium Salinity Salt Pond	"	9,901
High Salinity Salt Pond	"	3,854
Inactive Salt Pond	"	12,768

These values pertain to the area defined by the historical extent of the tides downstream of the confluence of the Sacramento and San Joaquin Rivers. Differences in total bayland acreage between these two columns represent amounts of land-use types not included in this analysis, including Undeveloped Islands or Fill, Salt Crystallizers, Tidal Marsh Channels, and Developed Baylands. For updated analyses and documentation, please see the Bay Area EcoAtlas Website at www.sfei.org. Version 1-50 used here, pre-release 2, 10/14/97.

SFEI, Bay Area EcoAtlas

Bay Area Mitigation Sites



Wetland creation, restoration and enhancement projects under Clean Water Act 401 and 404 permits.

SFBRWQCB

EXOTIC PLANTS

Exotic plants continue to spread along the Bay's shoreline and up into creeks. A smooth cordgrass (*Spartina alterniflora*) from the Atlantic coast is displacing the Pacific coast native (*Spartina foliosa*) throughout the marshes south of the Bay Bridge, and seed abundance of the non-native is on the rise in sediments. The Atlantic invader encourages sedimentation and clogs tidal channels — impacting California clapper rails that rely on this habitat. The invader is now so widespread that control measures can no longer be limited to on-the-ground removal. Indeed aerial spraying is now being seriously considered by wetland and wildlife managers (Josselyn, Pers. Comm.). Another invader called peppergrass (*Lepidium latifolium*) has spread over hundreds of acres of the Point Edith Marsh near Martinez (Malamud-Oram, Pers. Comm.). Water hyacinths continue to clog Delta waterways and pose boating hazards. The newest invader on the Estuary frontier is the giant reed (*Arundo donax*). This so-called "plant from hell" spreads easily, produces towering stalks and tenacious roots, outcompetes native plants, guzzles three times the water of native plants and offers no food, habitat or shade value to fish and wildlife in creeks and rivers. To date, this plant has invaded at least the Russian River, Napa River, Sonoma Creek and San Pedro Creek. Agency managers and scientists are now actively working on a control plan.

Shorebirds in San Francisco Bay

	SPRING	WINTER
1988		838,470
1989	931,561	225,427
1990	663,790	357,754
1991	588,964	342,504
1992	692,959	325,449
1993	627,093	

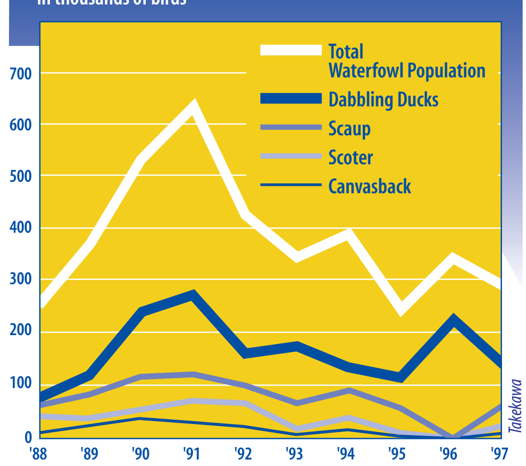
SHOREBIRD MIGRATIONS

S. F. Bay remains one of the most important stopovers on the Pacific Flyway for migrating shorebirds. Though recent censuses show a moderate decline in Bay shorebird populations between 1988 and 1993, data sets do not exist for enough years to establish trends. A 1996 spring shorebird survey of the South Bay counted 170,326 birds, dominated by species such as the American avocet, willet, black-bellied plover and marbled godwit. According to some estimates, up to a million shorebirds can be found passing through the Bay on a single day during peak spring migration periods. PRBO & SFBBO

WATERFOWL USE

S.F. Bay supports one of the largest populations of waterfowl in the Pacific Flyway during the winter and more than 50% of diving ducks in California (Accurso 1992). Although the timing of peak waterfowl populations varies greatly among years, three hundred thousand birds representing at least 32 species have been counted during annual January midwinter surveys in the Estuary. During the past decade, however, waterfowl counts in the Estuary have decreased. For example, though the Estuary has been recognized as one of the most important wintering areas for canvasbacks (*Aythya valisineria*), the local population of this species decreased from more than 60,000 in the 1970s to fewer than 30,000 in the mid 1980s, and continued to decrease in midwinter surveys over the past decade. Such decreases may indicate movements of birds rather than population losses, however. Early in the decade, several years of drought may have reduced the availability of Central Valley wetland habitats during the early winter, resulting in increased use of the Estuary through January. Recent wetland improvements under the Central Valley Habitat Joint Venture may have resulted in movement of species such as canvasback to interior wetlands. Continent-wide population decline of some species, such as scaup (*A. affinis* and *A. marila*) and northern pintail (*Anas acuta*), are reflected in the Bay populations. Management concerns for waterfowl include urban encroachment, effects of contaminants and alteration of diet through the introduction of non-native invertebrates in the benthic community (Takekawa, Pers. Comm.).

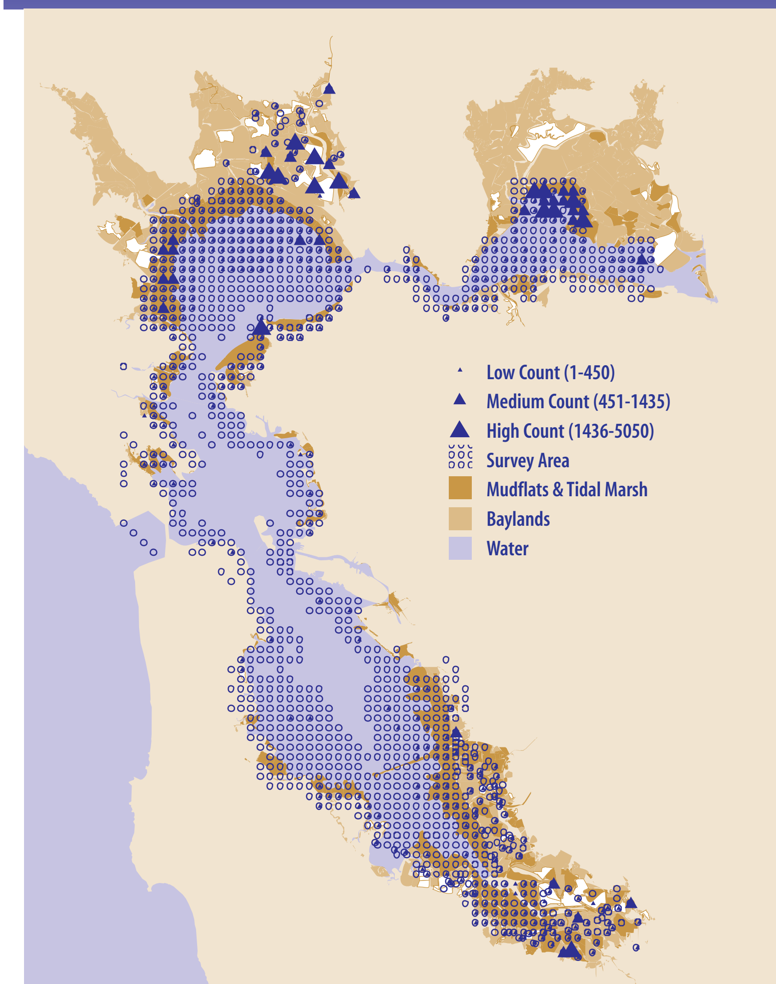
Waterfowl Population Trends
in thousands of birds



CLAPPER RAILS

The endangered California clapper rail (*Rallus longirostris obsoletus*) has declined from tens of thousands at the turn of the century to fewer than 6,000 individual birds in the 1970s and to fewer than 1,500 in the 1980s. Though rails are more abundant in the South Bay, the North Bay population is more stable — perhaps due to the higher, more mature nature of their habitat (where they are less often driven from cover into the jaws and beaks of predators). In general, recent rail declines have been attributed to increased predation on adult birds and eggs (particularly by the non-native red fox), increased levels of toxic substances in marsh sediments and insufficient emergent vegetation in which nests may be hidden (Foin et al. 1997). However, the rail's Bay population has grown from an all-time low of about 500 in 1991 to 1,200 in recent years.

Distribution of Canvasbacks (*Aythya valisineria*)
in open bays and salt ponds of the San Francisco Bay Estuary from 26 semimonthly aerial surveys, 1988-1990



Takekawa, Unpublished Data

BLACK RAILS

Black rail populations in the Bay region have not decreased since 1986. This state "threatened species" is smaller and more furtive than its endangered clapper cousin. A recent survey suggests 4,000-8,000 black rails inhabit the Suisun Bay area, and another 4,000-8,000 the San Pablo Bay area. There appear to be no black rails in the Central and South Bay (Nur et al. 1997). This tiny black bird prefers well-vegetated higher marsh — usually the first places to be developed on the shoreline. Development and predation by rats, cats, hawks and egrets continue to threaten its North Bay holdouts, but restoration plans for the area bode well for the species.

SALT MARSH SONG SPARROWS

Densities of salt marsh song sparrows — a useful indicator species of marsh health — appear to be lower in the Central and South Bay (median 3.7 birds per hectare) than in San Pablo Bay (median 18 birds per hectare) or in Suisun Bay (26 birds per hectare). Densities reported include both breeders and non-breeders. There are three sub-species of song sparrows in the Bay region. Current population estimates for the number of breeding Alameda song sparrows are 4,000-9,700 birds; for Samuel's song sparrows (San Pablo Bay), 22,000-53,000 birds; and Suisun song sparrows, 25,000-60,000 birds. In contrast, 1994 estimates were 14,800 of the Alameda sub-species, 19,100 of the Suisun sub-species and 31,200 of the Samuel song sparrow (Marshall & Dedrick 1994). Thus the population of the Alameda sub-species is at least 50% less than previously thought. Not only do breeding populations appear to be low, but habitat for this subspecies is the most compromised of the three. Researchers recommend that the Alameda song sparrow be classified as a threatened species and believe that the future of the other two subspecies is cause for concern (Nur et al. 1997).

California Least Tern Nesting
Alameda Naval Air Station

YEAR	MAXIMUM NUMBER OF PAIRS	MAXIMUM NUMBER OF FLEDGINGS
1976	10	NA
1977	45	NA
1978	80	13
1979	40	NA
1980	77	8
1981	74	103
1982	70	0
1983	3	1
1984	47	10
1985	53	60
1986	53	88
1987	59	97
1988	67	87
1989	75	93
1990	99	108
1991	112	144
1992	130	221
1993	128	210
1994	138	206
1995	150	73
1996	208	233

Collins

LEAST TERN NESTING

California least terns — an endangered species — are making a comeback statewide, after a major decline in the late 1970s and early 1980s. Almost all of today's least tern nesting in Northern California takes place at the Alameda Naval Air Station, where 208 pairs produced 233 fledglings in 1996 — a 28% increase in breeding pairs over 1995. The size of the station's breeding population — 7% of the state's total of 3,020 pairs — makes it one of the most important colonies in California. To protect this colony, plans for the upcoming base closure include establishment of a new wildlife refuge. The Bay includes two other least tern nesting sites. One site at the Metropolitan Oakland International Airport failed to host nests from 1992-1994, or in 1996, and all of the 1995 nests (up to six pairs) failed. One reason may be predation by the non-native red fox. With comprehensive fox controls, terns could be expected to nest regularly at the site again. The Bay's third nesting site — a PG&E cooling pond in Pittsburg — continues to sustain 2-4 pairs. Despite a promising comeback, the least tern's future continues to be endangered by habitat loss, as well as problems with humans and predators (Collins & Feeney, Pers. Comm.).

SALT MARSH HARVEST MICE

The status of the Bay's endangered salt marsh harvest mice hasn't changed much over the past few years. Small and very small populations (a few mice per acre) can still be found in many locations around the Estuary in habitats that are marginal at best; a few areas with higher quality vegetation and escape cover contain larger populations. Recent surveys indicate two locations of current concern for the mice. On the dark side, South Bay mouse habitat is deteriorating rapidly due to freshening by sewage plant effluent. On the bright side, North Bay marshes around Mare Island support consistently large mice populations. Plans for the Mare Island base's closure, combined with proposed restoration of part of the nearby Napa marshes, bode well for the mouse (Shellhammer, Pers.Comm.).

HARBOR SEALS

Counts and observations of harbor seals at haul-out sites in S.F. Bay in 1989-1992 and in 1995-1996 show a slight but not significant overall decline. The absence of growth contrasts with seal numbers along the outer California coast, however, which have increased significantly since federal protection in 1972. The three largest haul-out sites are Castro Rocks under the Richmond Bridge (the four-year-average population was 85 seals), the Central Bay's Yerba Buena Island (76 seals) and the South Bay's Mowry Slough (81 seals). Harbor seals tagged at the latter site consistently remained there during spring pupping and summer molt but moved on to other haul-outs during the fall and winter. Scat analysis indicated that the fish species most consumed (in mass) by the Bay seals were plainfin midshipman, yellowfin goby and white croaker (Kopec, SOE, 1996).

New Science

HISTORIC MARSH CONDITIONS

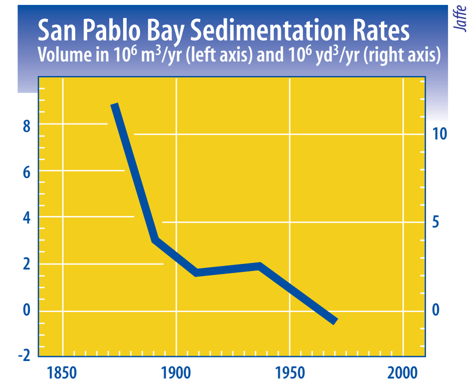
There was no long-term basic equilibrium of tidal wetlands around the Bay and freshwater wetlands in the Delta before human interference in estuarine hydrology began. Core samples of a freshwater (Rush Ranch) and a saltwater (Petaluma) marsh show that both areas rose about a millimeter and a half a year over the last 1,000 or more years, at about the same rate as the sea-level rise over the past 150 years. In addition, pollen analysis shows that the Petaluma site changed from brackish tule marsh (1,800 years ago) to saline pickleweed marsh (1,400-800 years ago) and back again (750 years ago). The Rush Ranch site has become significantly less saline over the last 600 years. These changes in vegetation make-up and rise of the marsh plain clearly correlate with long-term climate changes and variations in freshwater inflow into the system (Byrne, SOE, 1996).

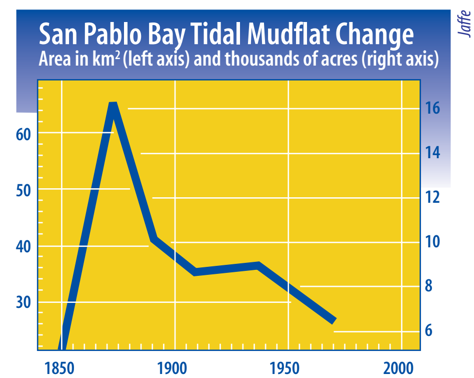
SEDIMENT DYNAMICS AND MUDFLAT CHANGE

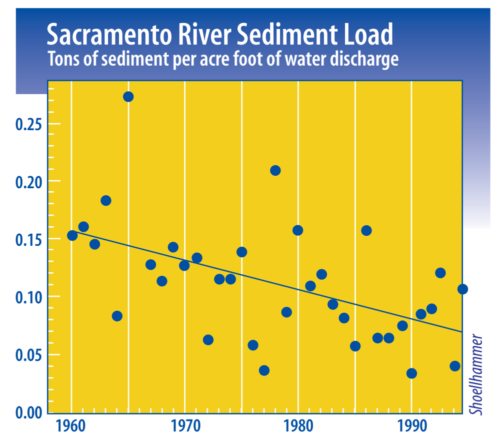
More than 350 million cubic meters of sediment were deposited in San Pablo Bay between 1856 and 1983. Over 2/3 of this sediment, however, was hydraulic mining debris that accumulated in only 21 years (between 1856 and 1887). Between 1951 and 1983, much of the Bay changed from being depositional to erosional in nature. The change probably occurred as a result of upstream flood control and Central Valley water projects, which reduced peak flows and associated sediment inputs (San Pablo Bay lost 7 million cubic meters of sediment from 1951-1983). One consequence of this reduction was the loss of over 60% (9,000 acres) of San Pablo Bay's tidal mudflats — rich habitats and sources of sediment for wetlands. Such changes in sedimentation must have affected the flow of water in the Bay, the exchange of sediment between the nearshore and wetlands, the erosional wave energy reaching the shoreline and locations of deposits of polluted sediments (Jaffe et al., SOE, 1996).

SEDIMENT SUPPLY

Sediment inputs into San Francisco Bay from the Sacramento River decreased between 1960 and 1995, diminishing the supply to wetlands. Between 1909 and 1966, the Central Valley provided 86% of the Estuary's supply, 84% of which came from the Sacramento River. But since then, Sacramento River inputs have markedly decreased — possibly due to increased reservoir capacity in the watershed. Surveys of San Pablo Bay reflect the diminished sediment supply, showing increasing water depth and decreasing mudflat surface area. As the Bay deepens and its mudflats shrink, the quantity of sediment resuspended by wind and waves also decreases, leaving less available for transport by tidal currents to wetlands. All these factors, combined with a rising sea level, reduce the likelihood that natural sedimentation rates can create new wetlands or restore former wetlands reopened to tidal action (Schoellhamer et al., SOE, 1996).







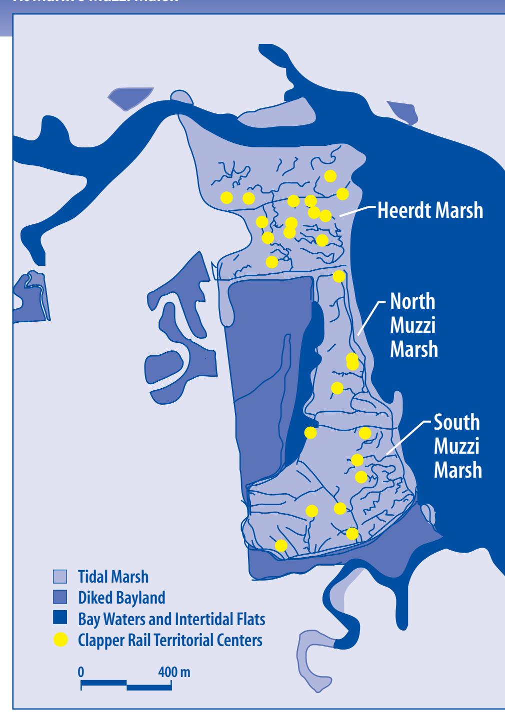
FACTORS IN WETLAND DIVERSITY

Recent scientific work has changed the way wetlands are defined, measured and viewed; revealed historical ecological changes in wetlands; and increased understanding of the relationships among wetlands, bays and watersheds. Three basic ideas have emerged from this work. First, the wetland ecosystem has a hierarchical structure. Smaller wetland habitats fit within larger habitats. The relationships among habitats and the wildlife they support are complex, but the habitats are clearly organized along spatial and temporal gradients, like ecosystem puzzle parts. Second, physical factors control the natural diversity of wetlands. The dominant physical factors are topography and climate. They control local and regional supplies of sediment and water, and thus they control the distribution and abundance of all our wetlands. For example, rainfall and runoff in local watersheds create estuarine gradients through the downstream reaches of every river and local creek. This means that the S. F. Estuary is actually a hierarchy of many smaller estuaries. Third, the regional mosaic of wetlands is a product of physical factors plus human land uses. There is strong evidence, for example, that the Ohlone people managed tidal marshes to harvest salt and waterfowl. After the Gold Rush, the historical expanse of tidal marshlands was reclaimed by immigrants for agriculture and expanded salt production. And some of these diked lands have since been dedicated to natural resources. Oxidation and hence subsidence of these diked lands inhibits their drainage and promotes the formation of seasonal wetlands. Some of these seasonal wetlands resemble the natural ponds of historical tidal marshes, but to what degree? These kinds of questions are accumulating for the region as a whole. They stem from a growing sense of dissatisfaction with some of the historical changes in our wetlands ecosystem. The historical perspective suggests that comparable changes will occur in the future, and that, to a large degree, people will control the future changes (Collins, SOE, 1996).

CLAPPER RAIL HABITAT

Clapper rails are more plentiful in the high marsh than previously thought. The highest densities of breeding pairs in five Marin marshes occurred in well-channelized pickleweed plain along second- and third-order channels. These new data suggest that rails don't seem to need cordgrass habitat — which scientists have long thought they preferred — to survive in healthy populations. High-marsh restoration may thus be even more important for clapper rails than low marsh. Indeed, low-marsh restoration of extensive stands of cordgrass can be much more difficult to achieve than encouraging development of tidal channels in the maturing high marsh (Foin et al.1997).

Clapper Rail Breeding Pair Territories
At Marin's Muzzi Marsh



Foin

MIGRATING PEEPS

A radio-tracking project in April 1995 and 1996 of 58 Western sandpipers (*Calidris mauri*) improved knowledge of how birds from the Bay migrate between coastal lagoons of California and nesting sites in Alaska. The tracking study yielded several interesting results. First, males dominated the early spring migration (April 10-20) and passed through the Bay before females (males generally winter farther north than females, so the later pulse of females through the Bay is probably from the southern-most wintering sites). Second, S.F. birds tracked via truck and airplane on their flight to Alaska stopped at all coastal sites monitored along the way. Birds tracked appeared to stop every 185-625 miles for rest and fuel, and 56% of them stopped at Alaska's Copper River Delta — making it the single most important stopover for birds marked in S.F. Bay. Most of the birds took 10-15 days to travel from San Francisco to the Copper River site, staying 1-4 days at each stop along the way (one bird astounded researchers by making the trip in 42 hours, or at over 44 miles per hour!). The Western sandpipers passing through S.F. Bay used all of the major coastal estuaries monitored in the 2,500 mile stretch between the Bay and the Yukon-Kuskokwim Delta, revealing the extraordinary interconnectedness of wetlands along the northwest coast and the importance of maintaining suitable habitat within this procession of estuaries and bays (Warnock & Bishop 1996).

YELLOW WARBLERS

Many urban creekside habitats are still being used extensively for resting and refueling by migrating neotropical birds. A long-term bird-banding program at the South Bay's Coyote Creek Riparian Station found that yellow warblers (*Dendroica petechia*) used the site for extended periods during the fall migration (mean of four days, range of 1-3 days). Of these resting birds, 57.9% gained mass, 15.8% maintained mass and 26.3% lost mass, indicating that most birds used the area for refueling. Fat load changes ranged from a loss of 1.5 grams to a gain of 5 grams (mean gain was 0.5 grams). Such gains were quite substantial considering the average mass of these birds is only 10.1 grams. Each gram of increased fat allows an individual bird to increase its flight range by over 560 km (Otahal, Unpublished Data). (See p.16 for more information on creeks.)

For information on contaminant levels and uptake in wetlands and wildlife see pp. 47-48. For more information on wetlands see Larsson p. 55, Grossinger pp. 55-56, Jackson p. 56 and Dingler p. 57.

SCIENTIFIC PERSPECTIVE

WHAT WE'VE LEARNED ABOUT WETLANDS

MIKE MONROE
Environmental Scientist
U.S. Environmental Protection Agency

Transcript of Summary of State of the Estuary Conference Wetlands Presentations

"For more than one hundred years, the wetlands around the Estuary have been severely affected by human activities. Now, with the days of rampant wetland filling behind us, we are moving into an era of increased appreciation of wetlands and the important role they play in the estuarine ecosystem. Three conference presentations touch on the interactions between wetland physical controls and their form and function. The fourth presentation describes a process underway for determining the kinds of wetlands that are needed to support a healthy Estuarine ecosystem.

"The diversity of wetlands around the Estuary is due primarily to three natural factors: topography, climate and tidal salinity. Topography, that is, the configuration of the land surface, determines the kinds of wetlands that occur near the Bay and upslope. For example, seasonal wetlands occur in topographical depressions; tidal marshes occur on the sediment plain adjacent to tidal waters. Climate, too, has a particularly strong influence on the evolution and maintenance of wetlands, especially through its effect on freshwater inflow. Water salinity also affects the kinds of wetlands that occur throughout the Estuary. This can be seen by noting the changes in vegetation along the salinity gradient from the Central Bay to the Delta; the kinds of wetlands that occur along this gradient are closely related to the short-term and long-term changes in salinity. It's important to note that humans, both past and present, have strongly influenced the structure of wetlands by altering and maintaining wetland habitats for salt production, hunting and other uses.

"Recent research refutes the view that all marshes around the Estuary have evolved to a mature state and will remain relatively static. Instead, long-term sea-level rise and climate change have extraordinary and little-appreciated effects on some of the Estuary's wetlands. Research at two North Bay marshes using radiocarbon dating methods to estimate the age of various sediment layers shows that the elevation of the tidal marsh plain has risen markedly over time, and that the water quality and vegetational makeup of these marshes has been far from constant. In the Petaluma Marsh and at Rush Ranch, researchers found that the elevation of the marsh plain rose at about the same rate as sea level rise (about 1.5 mm per year) during the past 800-1,000 years. From this, they conclude that the elevation of the marsh plain increased in concert with sea level rise. Water quality and vegetation in these marshes also changed historically. Some 1,800 years ago, the Petaluma Marsh was fairly brackish, characterized by tules. Sometime between 1,400 years ago and 800 years ago, the marsh became saline and was characterized by pickleweed. About 750 years ago, it again became brackish. Similar changes in vegetation are noted for Rush Ranch. The major changes in the vegetation make-up of these marshes over time probably reflects long-term climate changes and related changes in freshwater flows into the Bay.

"Sediment supply is another important factor that influences estuarine wetlands, as sediment is needed for wetland maintenance and creation. Rivers are the main sources of this sediment. River-borne sediments enter the Estuary and are resuspended, particularly by spring tides, and in the shallows and mudflat areas by wind-driven waves at high tide. The constant incoming flush of material that's churned and transported to the edge of the Estuary supplies sediments to the tidal marshes. Research shows that, between 1909 and 1966, the Central Valley tributaries supplied about 86% of the sediment coming into the Estuary. The Sacramento River was responsible for about 90% of this amount. Recently, we've found that the Sacramento River sediment supply has dropped markedly (a result of dams trapping material upstream), while the San Joaquin River supply has stayed fairly constant. One indicator of this declining sediment supply is the lowering of the bottom of San Pablo Bay as tidal currents move more sediments out of the system than are redeposited. As sea level rises, and it probably will rise faster in the future than it has in the recent past, the declining sediment supply will reduce the chance that natural sedimentation will provide enough sediment to maintain existing tidal marshes.

"Somewhat removed from research is a wetlands planning project that has been underway since mid-1995. Known as the San Francisco Bay Area Wetlands Ecosystem Goals Project, this effort will lead to the development of a vision of the kinds, amounts and distribution of wetlands needed to support a healthy ecosystem in the Bay Area. With many entities wanting to restore or enhance the Estuary's wetlands, there is a need for some kind of overarching view to guide these activities. More than 100 biologists and physical scientists are now working to develop wetlands goals. This includes assessing the needs of nearly 200 species of plants, fish and wildlife, and then determining the mix and extent of wetlands needed to support them. Once established, the goals will form the scientific basis for the preparation of a Regional Wetlands Management Plan."

Management Changes

NO-NET-LOSS POLICY

California adopted a statewide "no-net loss" policy in 1993 as part of Governor Wilson's wetland initiative. This policy emphasizes avoidance of destruction or degradation of wetlands.

CALFED RESTORATION EFFORTS

Local interests and the state and federal governments have cooperatively raised millions of dollars for ecosystem restoration over the last few years. Under the Category III program of the Bay-Delta Accord, stakeholder contributions are now funding $21 million in on-the-ground projects; including shallow-water habitat on Prospect Island, levee-related habitat on Sherman Island, riparian habitat on Butte Creek and Sacramento River and tidal wetlands on Decker Island. More projects will be identified for funding through Category III (up to $10 million more in 1997) and state Proposition 204 (up to $60 million) this year. Long-term restoration goals on an Estuarywide scale are now being developed as part of CALFED's common ecosystem restoration plan. As of April 1997, this draft plan called for restoration of 75,000-120,000 acres of freshwater and brackish tidal marsh and shallow-water habitat, as well as of 100-200 miles of riparian woodland and shaded riverine areas. The plan also proposes restoration of grassland and management of agricultural land to improve habitat values, as well as calling for the management of undesirable introduced species.

Courtesy San Jose Housing Department

Santa Clara County was one of the first local governments to incorporate wetland, watershed and stream protection policies in its General Plan and to pass a stream-protection ordinance. On a more sub-regional scale, eight local North Bay governments are now working in voluntary partnership with the S.F. Bay Commission to develop wetland protection and enhancement tools, policies and plans for their area. Vision for both efforts can be traced back to the S.F. Estuary Project's CCMP. Indeed, in 1996, Friends of the S.F. Estuary recognized Santa Clara's General Plan as an "Outstanding CCMP Implementation Effort."

BAY WETLAND GOALS

Regional leaders launched a science-based effort in mid-1995 to identify the types, amounts and distribution of wetlands needed to sustain a diverse and healthy Bay ecosystem. The S.F. Bay Area Wetlands Ecosystem Goals Project is a spin-off of the S.F. Estuary Project's *Comprehensive Conservation and Management Plan* (CCMP) for the Bay and Delta and offers the first biologically sound foundation for any future regional wetlands protection and management plan. The goals will also help guide and assist landowners, city and county planners, resource managers and other decisionmakers involved in land-use planning and Bay Area wetland protection programs.

CCMP IMPLEMENTATION PRIORITY

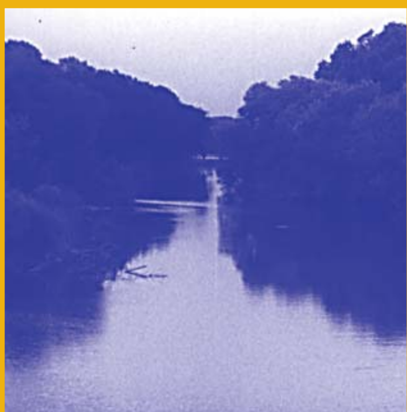
Diverse Bay-Delta interests agreed after a 1996 workshop that, among the CCMP's 145 actions, one of the ten top priorities should be restoring and protecting wetlands.

RESTORATION THRUST

A groundswell of wetland, creek, riverbank and watershed restoration projects is now sweeping the Bay and Delta. Government agencies and local citizens are becoming increasingly involved in such stewardship efforts. Over 8,000 acres have been enhanced or restored since 1993, and another 25,000 acres are planned or underway (SFEP 1996). Restoration of tidal action to former wetlands, particularly diked farmed baylands and salt ponds, is particularly popular. Around 40,000 acres of the San Pablo Bay shoreline are the new focus for such efforts, having been identified by scientists and resource managers as the Bay region's best candidate area for large-scale restoration of tidal marsh. Concerns remain, however, over whether the "restored" wetlands are equal in value to natural or existing marginal wetlands at restoration sites. Many feel, for example, that tidal marsh restoration should not occur at the expense of seasonal wetlands functions.

MITIGATION INNOVATION

Mitigation banking as a supposedly more ecologically sound alternative to piecemeal, project-by-project mitigation has gained strong support among many government leaders and business interests. The S.F. Bay Commission, with the support of the California Resources Agency, for example, is considering setting up a regional banking system of wetland credits and debits for small fills. The S.F. Regional Board is also evaluating mitigation banking as a regulatory tool. Meanwhile, several mitigation banks are in some stage of creation or operation in the state. Environmental interests remain extremely concerned, however, about the comparative biological and regulatory benefits of this new approach.



Courtesy Nature Conservancy

The last unregulated river flowing west out of the Sierra Nevada into the Delta is the 80-mile Cosumnes. Responding to ongoing threats to the river from urban expansion, The Nature Conservancy established the Cosumnes River Preserve in 1987, mainly to protect the excellent examples of valley oak riparian forest remaining in the lower reaches of the river and the prime wintering waterfowl habitat in its flooded bottomlands. It soon became clear, however, that these habitats could not survive in a preserve isolated from the river and the Delta. So the Conservancy broadened the preservation effort, seeking to restore and protect the integrity of the river's entire 1,250-square-mile watershed and ecosystem. To date, this massive effort has involved expanding the size of the preserve, restoring tidal marshes, re-opening floodplains by breaching levees, protecting forest habitats, establishing rice and pasture rotation on preserve farmlands to benefit both wildlife and farmers and providing an outreach and education program. A broad coalition of agencies, including the Conservancy, Ducks Unlimited, the Bureau of Land Management, the California Wildlife Conservation Board, Sacramento County and the American Farmland Trust, support the project, recognizing its significant contribution to their respective missions. In 1996, the S. F. Estuary Project recognized the Cosumnes River Project as an "Outstanding CCMP Implementation Effort."

BAY WETLAND ACQUISITION PARTNERSHIP

The San Francisco Bay Joint Venture, created in 1995, is acquiring, restoring and enhancing wetlands by leveraging existing public and private resources, developing new funding sources and creating public-private partnerships among 28 government and private interests. Since its creation, the Joint Venture has assisted partners with major projects, such as an enhancement plan for Pillar Point Marsh, acquisition of 109 acres of Bull Island wetlands in the North Bay and enhancement of the South Bay's Ora Loma Marsh.

NORTH BAY WETLAND PLANNING

Regional interests launched three cooperative planning efforts for the North Bay in the early 1990s. Save the Bay's Partnership for San Pablo Baylands is working with private landowners to promote grassroots support for San Pablo Baylands' protection. U.S. EPA's North Bay Forum is working to implement and coordinate the wetland and watershed resource management and regulatory activities of a dozen or more government agencies. The S.F. Bay Commission's North Bay Wetlands Protection Program is working with eight local governments to improve local protection of wetlands through land-use decision making.

RECOVERY PLANS

U.S. Fish & Wildlife is leading an effort to draft a Coastal Salt Marsh Ecosystem Recovery Plan that integrates, for the first time, actions needed to protect all the endangered species found in salt marshes. The plan updates and merges recovery actions for the California clapper rail and the salt marsh harvest mouse, as well as for other endangered birds, mammals and plant species. A recovery plan for the Western snowy plover is now being written, and a vernal pool recovery planning team was appointed in early 1997.

HABITAT CONSERVATION PLANS

Several Bay-Delta counties are developing Habitat Conservation Plans to provide development guidance on local protection priorities for sensitive wildlife and habitat. Yolo County's 1996 *Habitat Management Plan*, for example, provides up-front, uniform guidelines for protecting the habitat of 29 target species, including 12 endangered species, from encroaching urbanization. The plan requires developers to mitigate for every acre of development at a one-to-one ratio. Developers may either pay a $2,630-per-acre fee, which will go towards securing conservation easements, or buy land of high habitat value that will be put aside in exchange for the land they develop.

PREDATOR CONTROL

Control of predators, especially non-natives, has emerged as one of the most pressing management challenges of the 1990s for those charged with protecting endangered birds on the Bayshore. At the S. F. Bay National Wildlife Refuge, two full-time staff now carry out red fox and feral cat control to protect clapper rails. The staff identify priority trapping areas — based on their importance to the clapper rail and the size of the marsh — and use soft-catch traps for foxes and cage traps for cats. Professional animal control services are also employed at least tern nesting sites in Oakland and Alameda, with good results. Conflicts with animal-rights activists and cat-lovers remain.

4 WATER & SEDIMENTS

Students from Richmond High sample water quality in wildcat creek (see p. 23)

Overview

In its natural state, the Bay-Delta Estuary exhibited few, if any, adverse effects from pollutants. The sediment and naturally occurring chemicals that entered from upstream were assimilated into the estuarine ecosystem. As urban, industrial and agricultural activities expanded throughout the watershed, pollutant loads and associated effects increased. Although most of the obvious impacts were caused by the discharge of large quantities of nutrients via sewage, toxic chemicals also affected organisms.

During the 1960s and 1970s, improved treatment of municipal wastes reduced nutrient loadings and halted the most obvious pollutant problems — algae blooms and low levels of dissolved oxygen — in many parts of the Bay and Delta. Although advanced treatment facilities also reduced the loading of some toxic trace elements, these pollutants continued to enter the Estuary's waters in large quantities, especially from uncontrolled sources. Today, increased nutrients and reduced oxygen pose little threat to the Estuary ecosystem, while toxic chemicals are the chief cause of concern.

Coutesy BayKeeper

Volunteer stencils "Don't Dump" on San Francisco storm drain.

As of 1991, 5,000-40,000 tons of at least 65 pollutants were entering the Estuary each year, and the quantity has most likely increased since then due to population growth and accompanying development (more recent Estuarywide estimates are not available). The bulk of these chemicals are carried in runoff from urban areas and farms. Effluent from municipal and industrial outfalls, dredging, atmospheric deposition, spills, mines and other sources contribute the remainder. Around the Estuary, there are over 50 publicly owned sewage treatment plants and 65 large industrial facilities that discharge approximately 900 million gallons of effluent into the water system annually.

Although programs are in place to regulate the discharge of all pollutants, large quantities continue to enter the Estuary. Compared to background or reference sites, many pollutants occur at elevated levels in waters, sediments and biota from some areas of the Estuary. Concentrations in sediments and biota are generally highest in harbors, marinas and industrial waterways. Bioassays of the Estuary's water, sediments and biota indicate that some existing pollutant concentrations may cause toxic effects. Bioassays of urban runoff, farm drainage and municipal and industrial effluent also often indicate evidence of toxicity. Other research shows that some Bay fish have damaged chromosomes and tissue abnormalities strongly correlated with high levels of organic pollutants; more recent research has found mercury and PCBs in fish at levels harmful for human consumption. Those pollutants of particular current concern to plant and animal life in the Estuary include: the trace metals cadmium, copper, mercury, nickel, selenium, silver and TBT; organochlorines and other pesticides, especially diazinon, chlorpyrifos and DDT; PCBs and dioxin; and petroleum hydrocarbons (such as PAHs).

During the past 30 years, giant strides have been made in addressing the Estuary's complex pollution problems. Today, however, a much more difficult task faces people who live and work the lands around the Estuary and far upstream — the task of lowering toxic pollutant levels until they no longer compromise the Estuary's water quality and biological resources. Accomplishing this will require immediate changes in industrial and agricultural practices, transportation patterns and personal habits (SFEP 1992). Reduction efforts in this decade have been targeted at specific problems — copper in the South Bay, mercury in the Cache Creek watershed, diazinon in urban and orchard runoff, selenium in oil refinery wastewater and irrigation drainage and particulate matter in runoff from city pavements and air pollution fallout.

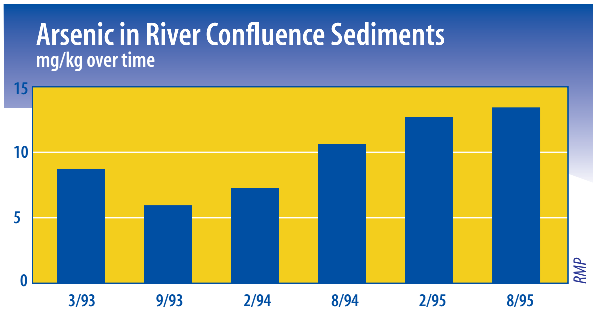
STATUS REPORT

HISTORIC CONTAMINANT TRENDS

Contaminant trends in S.F. Bay reflect the ever-changing balance between the processes that release wastes and those that mitigate contaminant impacts. Contaminant concentrations increased rapidly in Bay sediments between approximately 1940 and 1975 because of mining inputs and growing discharges from industrial and urban sources. Little advanced waste treatment was employed to remove contaminants during that time, and reductions in river inflows may have increased the Estuary's efficiency in trapping contaminants. By 1970, organisms in the Bay were exposed to a mixture of high concentrations of sediment-bound mercury, silver, lead, copper, DDT and PCBs; obvious contaminant impacts were evident in the food web. Contaminant inputs declined between the mid-1970s and today because of investments in advanced waste treatment, as well as cessation of mining and some types of industrial activity. The Bay has begun to cleanse itself of at least some types of contamination, on the time scale of decades; however some historical contamination is being redistributed. PAH concentrations in sediments have not declined to the extent of some other contaminants. Upper trophic level birds and fish still carry high burdens of some chlorinated hydrocarbons, like PCBs. Selenium contamination problems have not been resolved and threaten fish and birds at the higher trophic levels; in fact selenium concentrations appear to have increased in recent years. TBT — a highly potent threat to mollusks — remains a concern because partial bans have only recently been implemented. Undoubtedly new chemicals are being released that cannot be detected by existing technologies. Inputs are not the only factor determining contaminant effects. Biological processes, such as phytoplankton blooms in the South Bay, can rapidly transform some contaminants over very short periods of time. The importance of chemical contamination compared to stressors such as water diversion remains difficult to resolve. Not all sources of contamination are well known, and stressors interact in complex ways. Ecological responses can cascade through food webs for decades, making interpretation even more difficult. The only way to appreciate the changing dimensions of the problems, and to solve them, is to maintain research and monitoring programs, and to demand that those programs become increasingly interdisciplinary and interactive (Luoma, SOE, 1996).

CURRENT POLLUTANT LOADS & TRENDS

As of 1991, 5,000 to 40,000 tons of pollutants were finding their way into the Estuary each year (SFEP 1991), and the amount has likely increased since then with recent population growth and development. The greatest uncontrolled sources are untreated urban and agricultural runoff (see also Ruby, p. 57), although stormwater control and watershed management programs increased dramatically with new regulations under Clean Water Act amendments. Over the past eight years, most contaminant concentrations have remained constant, with some seasonal and annual fluctuations. Several long-term trends have emerged, however. Arsenic in the sediments at the confluence of the Estuary's main rivers appears to be on the rise, for example. PCB concentrations in Central Bay water and sediments appear to be decreasing. Diazinon, a common orchard and garden pesticide, is turning up throughout the estuarine ecosystem at concentrations lethal to sensitive organisms. Mercury from abandoned mines and selenium from agricultural drainage continue to be a problem upstream. The largest biological effects resulting from Estuary pollution are observed in the North Bay region at the Napa River, Suisun Bay and the confluence of the Sacramento and San Joaquin rivers (where trace metals from mine runoff may have accumulated in sediments and where pulses of pesticides from farm drainage converge). The incidence of biological effects is generally lower in the Central Bay — flushed daily by strong tidal action — and moderate in the South Bay (an enclosed, shallow area where pollutants may concentrate) (RMP 1995).



DIAZINON & CO.

Pesticides regularly enter the Estuary via runoff from agricultural and urban landscapes and atmospheric fallout from aerial spraying. Of particular concern is the near million pounds of diazinon, chlorpyrifos, malathion and methidathion applied on about half a million acres of Central Valley stonefruit orchards every year to control wood-boring insects. All four chemicals have been detected in surface water (see p. 46); however, diazinon and chlorpyrifos appear to pose the greatest threat to aquatic organisms. In a multi-rivershed study conducted during the 1992 rainy season, 30% of all water samples turned up toxic, and diazinon appeared in 90% of the toxic samples (Foe 1993, 1995). In cities, pesticides sprayed on gardens, fruit trees and landscaping are also turning up in streams and stormwater. In 1994-1995 tests of urban streams in Sacramento and Stockton, levels of diazinon and chlorpyrifos exceeded Cal Fish & Game's recommended water-quality criterion in 80% or more of samples. Approximately 50% of samples collected from Bay Area streams in the same period exceeded the criterion for diazinon, and 75% of samples exceeded the criterion for chlorpyrifos (Bailey et. al., SOE, 1996). Diazinon is one of the most commonly used general purpose pesticides in California. In a Palo Alto study, 50%-60% of the 3,300 lbs. purchased per year in the area was used to control grubs, ants and fleas around homes and gardens. In a 1994-1995 sampling of water in four Palo Alto area creeks, diazinon occurred in concentrations up to 400 ppt (80 ppt is the maximum recommended by the state to protect aquatic life) (Cooper 1996). Diazinon levels in Castro Valley street gutters reached over 50,000 ppt in 1996.

Diazinon in Rain Samples
Northern California cities
Concentration in parts per trillion on 2/8/95

Red Bluff	4090
Hamilton City	1956
Colusa	418
Yuba City	3957
Nicolaus	4460
Davis	885
Sacramento	700
South Sacramento	1225
North Stockton	842
Central Stockton	2352
Central Stockton	1300
South Stockton	3729
Albany	88
Tracy	4181
Patterson	5463

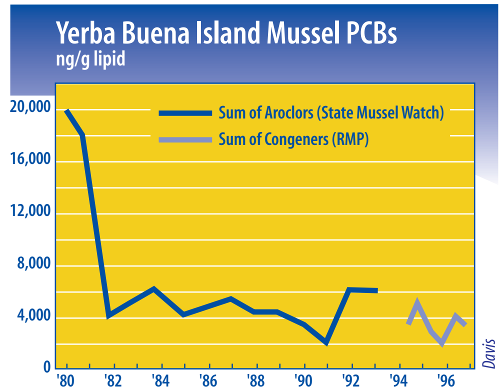
Connor

For comparison the Cal Fish & Game maximum criterion for impacts on aquatic life is 80 ppt.

PAHs

Concentrations of polynuclear aromatic hydrocarbons (PAHs) were frequently above water-quality criteria at Bay monitoring stations between 1993-1995. In high concentrations, PAHs (particularly the "3-to-5-ring" variety) can be chronically toxic to aquatic organisms. PAHs tend to concentrate in the more urban portions of the Estuary and derive from fossil fuel combustion, chemical and microbial activity in sediments and thermal conversion of chemically complex geological deposits. They enter the Estuary via atmospheric and riverine inputs, runoff, accidental spills, wastewater discharges and sediment changes. In 1994, RMP samples of Estuary water indicated that dissolved PAHs (the sum of 15-16 individual PAH compounds) were between 0.07-17.3 ppt (parts per trillion). In 1995, the range (for 13 compounds) was 0.39 - 8.24 ppt. When both dissolved and suspended PAHs in Bay water are considered, concentrations ranged from 2.8 to 504.9 ppt in 1995, and 38% of samples exceeded the EPA water-quality criterion of 31 ppt. In 1995, PAHs in sediments ranged from 16-3,722 ppb. Seasonal effects were not apparent in water sampling, but in sediment samples, winter had the highest PAH concentrations (Spies, SOE, 1996 and RMP 1995).

PCBs & DDT



Concentrations of PCBs in water were considerably higher than EPA water-quality criteria at all 24 monitoring stations of the Bay's Regional Monitoring Program (RMP) in 1993-1996. Organochlorines, such as PCBs and DDT, are among the most toxic pollutants. Although banned for more than 20 years and declining over the long run, these chemicals persist in the estuarine environment and continue to bioaccumulate in fish, seals and waterfowl. In the same period, the RMP found DDT concentrations in sediment samples above effects-range guidelines at many stations (RMP 1995).

TRACE METALS

Trace metals continue to reach levels of concern in water or sediments from the South Bay, Suisun Bay and several Delta waterways. Concentrations of chromium, copper, lead, mercury and nickel at Bay monitoring stations occasionally exceeded water-quality objectives in 1995 and 1996. Most elevated concentrations were found in the Northern Estuary and the South Bay. In sediments, nickel had concentrations consistently above guidelines (nickel occurs naturally in the region's serpentine soils). Arsenic, chromium, copper and mercury levels exceeded sediment guideline concentrations at most stations throughout the Estuary during all sampling periods. Selenium continues to be a problem in Suisun Bay, where levels in clams are higher than previously thought and where this metal bioaccumulates to harmful levels in invertebrates, fish and birds. Such levels may be influenced by the invading clam *Potamocorbula* (which concentrates 2-3 times as much selenium in its tissues as other residents) and by river inflows. Low concentrations in clams coincide with high flows (RMP 1995). Selenium is conveyed to the Estuary via San Joaquin Valley agricultural drainage and North Bay oil refinery wastewater discharges. Sources of problem copper levels in the South Bay now receiving attention include discharges from metal finishing and circuit board manufacturing industries and runoff from auto brake pads. A probable major source of mercury inputs to the Estuary was recently identified by the Central Valley Regional Board as the Cache Creek watershed. During a peak storm period in January 1995, mercury levels at the creek's confluence at the Yolo Bypass were measured at 695 parts per trillion (EPA water-quality criteria is 12 ppt). Abandoned mines are a possible source of the mercury, as well as of many other metal inputs to the upper Estuary.

AQUATIC TOXICITY TRENDS

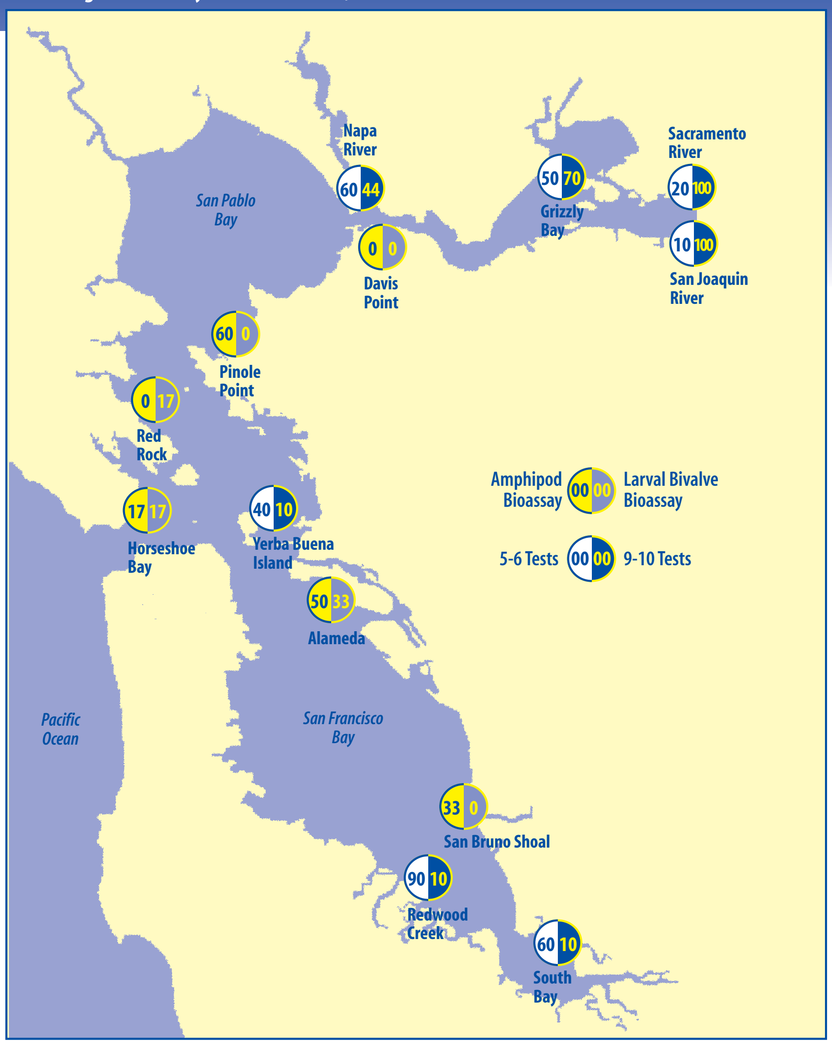
Toxicity to mysids (a small shrimplike zooplankton) was observed in 46% of water samples collected from the Sacramento River, San Joaquin River, Grizzly Bay and Napa River regional monitoring stations between 1994 and February 1997. Toxicity was assessed using a bioassay test in which mysids were placed in ambient water samples for seven days to measure their survival rate. By contrast, no toxicity has been observed since 1993 in another test using larval bivalves. Toxicity was less frequent in 1994 and 1995 than in 1996 and 1997. Beginning in February 1996, toxicity occurred in almost all samples at the four stations, and in February 1996 and 1997, was so severe at the San Joaquin River station that none of the mysids survived at all. In contrast, aquatic toxicity has only occurred in one other sample in the Estuary (Red Rock near the Richmond Bridge, February 1994) since testing began in 1993. Because of the location near the Bayward end of large rivers, and the time of year that toxicity was observed, dissolved pesticides are the suspected source of the toxicity (RMP News 1997).

SEDIMENT TOXICITY TRENDS

Sediments from nearly all RMP monitoring sites are often toxic to test organisms (despite having been picked to represent some of the cleaner sites in the Bay). Overall, toxic sediment has been found most frequently in Suisun Bay; most consistently in Redwood Creek, the Napa River, and at the confluence of the Sacramento and San Joaquin rivers; and never at Davis Point in the San Pablo Bay. The causes of this toxicity are poorly understood but seem to be partially related to the presence of chlordanes at some sites, PAHs at Central Bay sites and metals at river sites. Some could be due to natural toxins in sediments, such as algae, hydrogen sulfide or ammonia; some could derive from the cumulative effect of a complex mixture of pollutants found in the Estuary. Bottom-dwelling organisms and communities in areas with sediment toxicity do not appear to be severely impacted, however (RMP 1995).

Incidence of Sediment Toxicity in S.F. Bay

Percentage of bioassays that were toxic, 1991-96



RMP

New Science

METAL TRANSPORT & BIOAVAILABILITY

The remobilization of cobalt (Co), nickel (Ni), copper (Cu) and zinc (Zn) in bottom sediments is greater than either riverine or point-source inputs of these elements to the Bay. Remobilization refers to the recycling or re-release of historic deposits of contaminants in benthic sediments via mechanical, chemical or biological processes. These benthic inputs will become an increasingly important source of pollution and contaminant bioavailability to estuarine organisms as human inputs from wastewater discharges, runoff and air pollution are slowly reduced. Remobilization may be one reason why North Bay trace metal concentrations have remained essentially unchanged over the last ten years and why some metals in the South Bay may continue to be elevated for decades. Adverse impacts from remobilization may also be exacerbated by future reductions in hydraulic flushing of the Estuary due to freshwater diversions or drought. In order to determine the extent of remobilization of five metals from Bay sediments, both dissolved and particle-associated concentrations were measured in both relatively pristine and contaminated sediments. While estimated benthic inputs of Ni, Cu and Cd were relatively small (< or = 10%) compared to their riverine inputs, Co and Zn were similar (100%) to their riverine inputs. However, estimates of benthic remobilization of total (dissolved and particulate) Co, Ni, Cu and Zn indicate that these are greater than either riverine or point-source inputs of these elements. Measurements of metals associated with "colloids" (particles between <0.2 microns and the size of a big organic molecule, i.e., small enough to stay suspended in the water and not settle down and be buried and assumed "neutralized") indicated that up to 84% of metals in rivers and 5-40% in the Bay are associated with colloids, but that colloids only transport a small fraction of the metals in the Estuary. Metal transport and bioavailability are not only influenced by the different size particles they associate with, but also by seasons, estuarine geography and their occurrence in various chemical and physical forms ("speciation"). In related South Bay studies (Donat 1994 & Miller 1995), for example, it was found that up to 90% of the copper occurs in a non-toxic organic form ("species") while most of the silver occurs in an inorganic form toxic to organisms (Rivera-Duarte & Flegal, SOE, 1996). (See also Kuwabara, p. 56).

Estimated Total Benthic Remobilization
in the South Bay

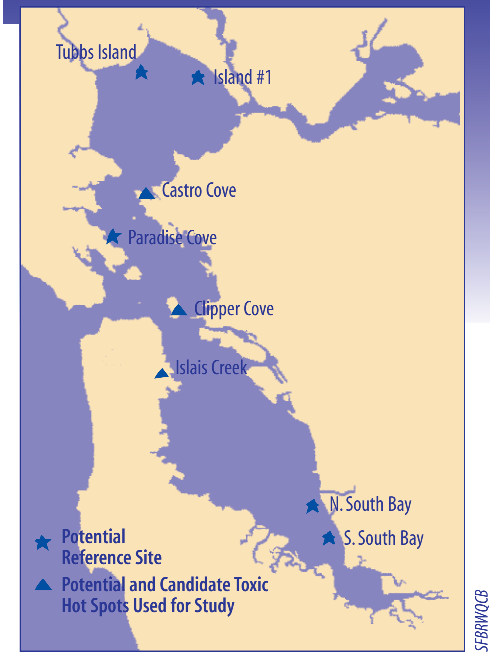
ELEMENT	BENTHIC KG/DAY	RIVERINE KG/DAY	BENTHIC RIVERINE %	POINT SOURCES KG/DAY	BENTHIC POINT SOURCES %
Co	—	1.0	—	NA	—
Ni	1,000	10.0	9,000	40	3,000
Cu	800	10.0	7,000	50	2,000
Zn	1,000	20.0	6,000	100	1,000
Cd	10	0.1	10,000	6	200

Rivera-Duarte & Fiegal

REFERENCE ENVELOPE

Five new reference sites for use in comparing the Bay's cleaner versus more toxic corners were identified in a 1994-1995 study. These candidate reference sites — whose sediments were run through 7-9 different toxicity tests and whose test results were then compared with results from three suspected toxic hot spots — showed consistently low contamination and toxicity to organisms. The sites include Tubbs Island and another site in the North Bay, Paradise Cove in the Central Bay and two South Bay locations. The purposes of the study were to develop better reference sites for ambient Bay conditions, to identify sites for clean up that are significantly more toxic than the references and to create more realistic toxicity tests for use by Bay dredgers, dischargers, toxic clean-up planners and regulators. Part of its impetus came in 1992, when long-thought pristine reference sites in Tomales Bay and Bolinas Lagoon yielded wildly variable results (sediments proved toxic to 20-90% of test organisms). The variability raised questions about the suitability not only of the sites as a consistent reference for regional natural background conditions, but also of the toxicity testing methods themselves. In addition to the five candidate reference sites, two of the nine possible toxicity tests have proved most useful and consistent — one placing amphipods (shrimp-like aquatic organisms) in sediments for ten days and measuring their survival and another placing sea urchin larvae in sediment cores and water and assessing their development. To date, 104 possible toxic hot spots have been screened using the new tests and reference sites approach. Final results on the reference sites study are due for release in fall 1997, and on the toxic hot spot screening in spring 1998 (SFEP 1995).

Reference Study Sites



PESTICIDE FATE & TRANSPORT

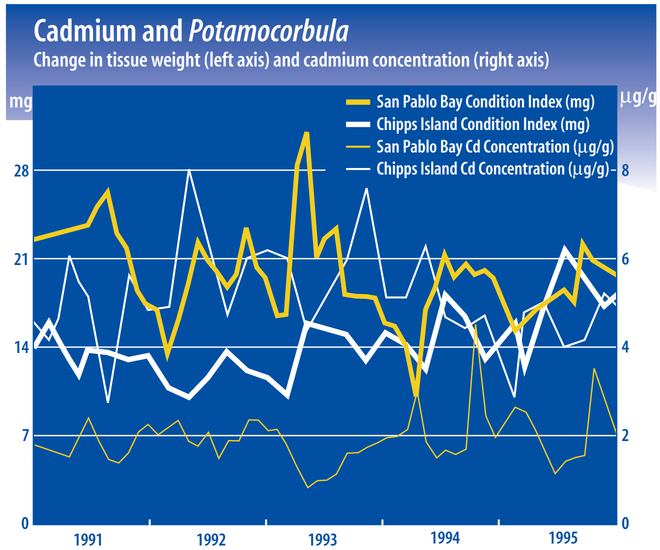
Pesticides applied to orchards, rice fields and other crops enter the Estuary. Dormant sprays — applied to stonefruit orchards during the dormant season of the trees in winter — enter waterways with the first rainfall after application. At this time, pulses of diazinon and methidathion have been observed in Sacramento and San Joaquin rivers and followed through Suisun Bay. In the rivers, the duration of the pesticide pulse is days to weeks; in the tidally influenced and more hydrodynamically complex Delta and Bay, the duration lasts weeks to months. Maximum concentrations of pesticides vary depending on the amount and timing of rainfall, and between 1991 and 1996 ranged from non-detectable to 16,000 ng/L(nanograms per liter) in the San Joaquin River at Vernalis.

Rice pesticides enter the Sacramento River with the release of rice field water in May and June. Beginning in 1989, regulations increased the holding time of water on the fields, allowing increased degradation of pesticides in the fields and resulting in lower concentrations of rice pesticides in the environment. In recent years, however, concentrations of molinate, thiobencarb and carbofuran were still detectable in the rivers, the Delta and Suisun Bay. For example, in May and June 1996, concentrations of molinate, thiobencarb and carbofuran were elevated for almost two months at Mallard Island, reaching maximum values of 630, 66 and 28 ng/L respectively. Besides rice and orchard pesticides, chemicals applied to row, truck and grain crops are also turning up in Estuary waterways. Following the first flush after the first winter rain, pulses of atrazine were detected in the Sacramento River (1992 and 1993), and pulses of dacthal and cyanazine were detected in the San Joaquin River (1993 and 1994). Metolachlor and cabaryl have also been detected at elevated levels. The complex hydrodynamics and many agricultural diversions and returns in the Delta make it difficult to determine the sources of these pesticides.

In terms of fate and transport of pesticides in general, concentrations were highest near the source, but varied from year to year. Also in general, the residence time of elevated concentrations increased from the rivers to Suisun Bay and the Delta (i.e., peak concentrations downstream were lower than in the rivers but lasted longer, which is important because biological effects are dependent on both concentration and exposure time) (Kuivila, SOE, 1996). (See also Bergermaschi pp. 56-57.)

METAL IMPACTS ON CLAM HEALTH

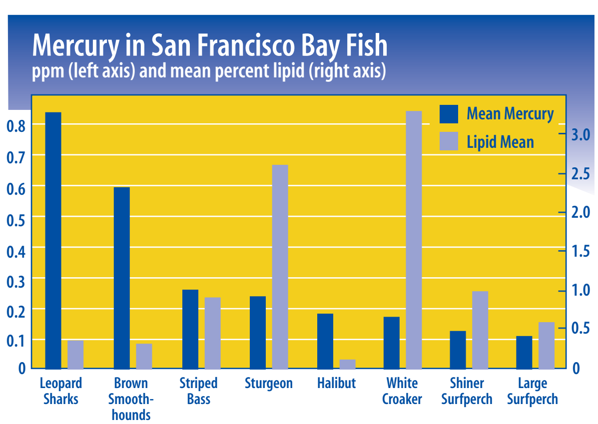
The condition and reproductive status of North Bay clams is impacted by chronic, low-level exposure to metals in water and sediments. The Asian clam *Potamocorbula amurensis* was examined within a reach of S.F. Bay with a known trace metal concentration gradient (concentration diminishes as you move seaward) between 1991-1995. Preliminary findings show that the condition (change in tissue weight for a 15mm animal) of this species decreases with increasing cadmium content; clams from Chipps Island in the upper Estuary have the highest cadmium concentration and lowest condition, and those from San Pablo Bay have the lowest cadmium concentrations and highest condition (Brown, SOE, 1996). High cadmium tissue concentrations (>5 µg/g — micrograms per gram) also coincide with asynchronous spawning (when populations do not spawn in synchrony, disrupting reproductive cycles), and no distinct seasonal cycle in the condition index. Low cadmium concentrations (<5 µg/g) coincide with synchronous spawning and a distinct seasonal cycle in the condition index. Some seasonal differences in condition could not be explained by reproductive activity alone. In most of these cases, food availability could account for most of the variability. The number of reproductive cycles, timing of reproduction, speed with which animals regain weight after spawning and amount of weight gained during spawning are most strongly related to food availability. But synchrony in spawning timing was apparently related to cadmium content in animals, as populations from the stations and periods with the highest cadmium concentrations had the most asynchronous spawning. Asynchrony is potentially deleterious to any organism — such as *Potamocorbula* — that depends on external fertilization (Thompson, SOE, 1996).



Brown

CONTAMINANTS IN BAY FISH

Six contaminants were found in Bay fish at levels exceeding EPA screening values for safe human consumption. In 1994, edible fish species (white croaker, surfperch, leopard and brown smoothhound sharks, striped bass, white sturgeon and halibut) were collected from thirteen locations throughout S. F. Bay to determine contaminant levels in muscle tissue. Tissue samples were analyzed for the presence of PAHs, PCBs, pesticides, trace elements and dioxin/furans. PCBs (as total Aroclors) exceeded the screening value of 3 ng/g (nanograms per gram) in all 66 muscle tissue samples, with the greatest concentrations (638 ng/g) found near San Francisco's industrial areas. Mercury was above the screening value (0.14 µg/g) in 40 of 66 samples, with the greatest concentration (1.26 µg/g) occurring in shark muscle tissues. Concentrations of the organochlorine pesticides dieldrin, total chlordane and total DDT exceeded screening values in a number of samples. Dioxin/furans were elevated (>0.15 pg/g) (picograms per gram) in 16 of 19 samples analyzed. Fish with high lipid content (croaker and surfperch) in their muscle tissue generally exhibited higher organic contaminant levels, while fish with low lipids (halibut and shark) had lower levels. Tissue samples taken from North Bay stations most often exhibited high levels of chemical contamination. The California Office of Health Hazard Assessment is currently evaluating the results of this study and has issued an interim Health Advisory concerning the human consumption of fish tissue from the Bay (Clark & Taberksi 1996). (See also Anderson, p. 57.)



Clark

METAL UPTAKE BY PICKLEWEED

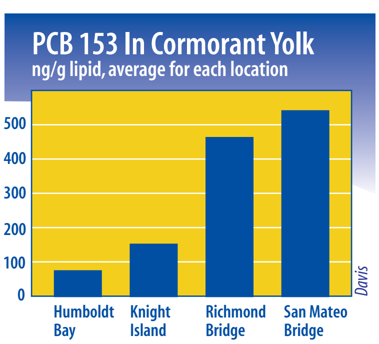
Pickleweed growing in a marsh that receives drainage discharges from the Hamilton Army Airfield runway and maintenance facilities does selectively uptake metals out of the soil. The species exhibits luxuriant uptake of magnesium, sodium and potassium (also key plant nutrients) and some uptake of copper, lead and nickel. However, arsenic, beryllium, cadmium and mercury were not detected in the pickleweed. Except for calcium, uptake did not correlate with metal concentrations in the sediment. For example, pickleweed shoots contained only 0.75 mg/kg dry weight of lead while growing in sediments with lead concentrations of 1540 mg/kg. Whether those metals that the pickleweed does take up then pose an ecological risk via the food chain is still not known (Demgen, SOE, 1996).

TOP OF THE FOOD CHAIN

DDT, PCBs, dioxin and selenium have all been found in Bay birds and marine mammals. Tests of black-crowned night herons found 2-6 ppm of DDE (a DDT derivative) — levels greater than 5-10 ppm can cause eggshell thinning in many species of birds. Levels of PCBs in Bay cormorant eggs are at threshold levels for causing developmental malformations and reduced breeding success (see below). Levels of selenium in Suisun Bay diving ducks, which consume bottom-dwelling clams such as *Corbicula* and *Potamocorbula,* have been measured at 30-50 ppm (skeletal malformations occur in mallard and shorebird embryos exposed to levels greater than 5-10 ppm). Scoters have been shown to have lower levels of some pollutants when they arrive in S.F. Bay than when they leave — suggesting they bioaccumulate the contaminants over the winter (Ohlendorf et al. 1991 and Fry, SOE, 1996). Marine mammals also bioaccumulate contaminants. Seal blood tested in the early 1990s indicated elevated organochlorine residues, selenium residues significantly higher than in seals sampled at a comparable non-Bay estuarine site and lead and cadmium residues in the range associated with mammalian toxicity. Copper residues were at background levels, and silver below the quantification limit (Kopec, SOE, 1996).

CORMORANTS & PCBs

PCBs appear to exert measurable toxic effects at the top of the S.F. Bay food web, despite 20 years of restrictions on their use. In 1994, double-crested cormorant eggs were collected from two sites in S.F. Bay (Richmond Bridge and San Mateo Bridge), one site adjacent to S.F. Bay (Knight Island) and another site in Humboldt Bay. The eggs were artificially incubated, and the hatchlings examined for possible effects due to organochlorine exposure. Mean PCB concentrations were essentially equivalent in the Richmond Bridge and San Mateo Bridge colonies, and were approximately 7 times higher than the Humboldt Bay mean. PCB congeners indicative of more highly chlorinated Aroclor mixtures were even more elevated in the San Francisco Bay colonies. Effects on double-crested cormorants associated with PCBs in this study include reduced egg mass, reduced spleen mass and increased levels of a liver enzyme (cytochrome P450) that is a marker of exposure to organic contaminants. The observations suggest possible detrimental effects on chick survival and immune competence. Populations of double-crested cormorants in San Francisco Bay have increased in recent years, however, so the apparent effects described have not been severe enough to limit the population. The collection and analysis of cormorant eggs proved to be an efficient, sensitive and relatively non-invasive means of measuring PCB accumulation and toxicity at the top of the food web (Davis 1997).



For more information on contaminants see pp. 54-57.

SCIENTIFIC PERSPECTIVE

WHAT WE'VE LEARNED ABOUT CONTAMINANTS

Summary of State of the Estuary Conference Pollution Presentations

DR. BRUCE THOMPSON
Environmental Scientist
San Francisco Estuary Institute

"Source-control and pollution-reduction programs in the Estuary are certainly some of our best successes. The large sewage treatment plants (POTWs) have drastically decreased the loadings and amounts of contaminants that they discharge into the Estuary in recent years. This is mainly through improved source-control programs — going back to the people who discharge these contaminants to [treatment plants] and the Estuary and helping them to understand how to pre-treat. This pollution-reduction trend is reflected in how contaminants are taken up by clams that live near the treatment outfalls. Over the last several decades, the amounts of silver or other metals in the tissues of these clams have followed the decreasing trends of the POTWs. Many of the contaminants in sediments are also decreasing over time, based on deep core samples that go back before industrialization. When you see industrialization, and the Gold Rush, you see an increase in the contaminant concentrations. Those hit their peaks usually around the 1940s-1960s. But almost without exception, contaminants are now decreasing back towards the background levels observed in pre-industrial times.

"Some of the greatest sources of contamination to the Estuary now are considered to be the non-point sources — untreated urban runoff, riverine inputs and, in particular, pesticides. Another major source is some of the historic deposits of contaminants which are still leaching slowly out of the sediments into the water column. In particular, copper, zinc, cadmium and PCBs are of concern. Another source, atmospheric deposition — the contributions from aerial fallout from materials put into the atmosphere — is largely unquantified and is one of the places we really need to examine.

"Turning to fate and transport of contaminants, trace metals concentrated in the Northern Estuary have remained rather constant in the past decade. We need to greatly update what we know about loadings from the rivers. We do know about pesticides from the Central Valley, however. These pesticides are applied on different crops at different times of the year, and, depending on rainfall, come in pulses down the main rivers. When the peaks are high, you get concentrated pulses that are quite toxic, at least in laboratory toxicity tests. Whether or not these have ecological or biological impacts to the Estuary is still being debated.

"Turning to biological effects, the Regional Monitoring Program has measured water quality in the Estuary for the last three years. We often find that certain contaminants exceed water-quality guidelines — the Regional Water Board's Basin Plan*, or EPA criteria in water, particularly for copper, nickel and mercury. PCBs exceed water-quality objectives in the water nearly every time, and just about everywhere. As a result of this, most fish exceeded screening levels for [human health risk] for PCBs, dioxins, some pesticides and mercury in 1995. In terms of PCBs, we see large reservoirs in the sediment that can very slowly leach into the water and then expose food chain organisms and end up in the fish, resulting in human health warnings.*

*"How do contaminants affect fish health? We've seen probable effects of contaminants on striped bass and starry flounder, possible effects on Delta smelt and selenium effects on sturgeon. Winter-run salmon have higher body burdens of many contaminants than one might expect. But it's not clear exactly what biological effects these are causing. It is clear, however, that North Bay clams (*Potamocorbula*) are generally unhealthy in terms of their condition and reproduction due to exposure to metals from the rivers. In addition, pesticide pulses coming down the river have caused toxicity to laboratory organisms. Other studies show that Estuary sediments are often quite toxic to test organisms. But the specific causes of all this toxicity are unknown, mainly because sediments are mixtures of contaminants.*

"Birds in the Estuary are near the threshold of expected contaminant effects, particularly for PCBs, dioxins and petroleum compounds. Selenium is also still a large problem in birds. The new clam — Potamocorbula *— has been shown to accumulate selenium at higher rates than some of the native clams, and they are looking at the increased potential for this to get into the fish and the birds.*

"In general, contaminants of concern in the Estuary are shifting from trace metals to organic compounds; however, selenium and mercury are still considered to be the two metals of the highest concern. PCBs are quite persistent; although they have been banned, they always exceed water-quality objectives. Dioxin and dioxin-like compounds are the next big question mark.

"So what are some of our options and solutions? Certainly, in terms of information gathering, we've seen better coordination than ever before. The S.F. Estuary Institute's Regional Monitoring Program, the Sacramento River Toxics Program, the Sacramento Coordinated Monitoring Program, the U.S. Geological Survey and the Interagency Ecological Program are all monitoring contaminants. We fully expect that in the next few years there will be a seamless contaminant monitoring program from Sacramento all the way down to the Golden Gate.

"Meanwhile, the Long-Term Management Strategy (LTMS) has been successful in developing protocols for dealing with contaminants in dredged sediments, and the state's Bay Protection Toxic Cleanup Program will soon identify some toxic hotspots we need to clean up. The next big challenge is the base closures and their legacy of contamination."

STORMWATER MANAGEMENT

Reducing pollution from stormwater has become a major focus in almost all the Estuary's major urban watersheds, with many improvements to existing stormwater management programs, as well as the creation of new programs. In 1995, the S.F. Regional Board reinforced the thrust for stormwater management through a new regional policy in its *Basin Plan*, and state policies were reinforced through a State Water Board update of its nonpoint source pollution control program for agricultural, urban, mine and marina runoff. As of spring 1996, municipalities with stormwater control programs were the cities within and counties of San Mateo, Santa Clara, Alameda and Contra Costa (except Brentwood); and the urban regions associated with Sacramento, Stockton, Vallejo and Fairfield-Suisun City. Baseline programs are in place for Marin, Napa and Sonoma counties. Bay Area agencies recently completed a regional analysis of all stormwater monitoring data collected since 1988 (BASMAA 1997).

Coutesy BayKeeper

A BayKeeper patrol nosing around a tanker. This citizen watchdog group, started in 1989, patrols the Bay looking for illegal discharges, fills and spills, brings lawsuits against polluters, and involves volunteers in good BayKeeping activities. In 1996, the group conducted over 300 pollution patrols and hundreds of site visits, spotlighted or took legal action against offenders ranging from a Petaluma feedlot to a South Bay metal finishing company and a Vallejo sanitation district, negotiated clean up of two dozen junkyards discharging contaminants into the Bay, and set up a floating laboratory for students to use in monitoring fecal coliform in the San Rafael Canal. At the 1996 State of the Estuary conference, BayKeeper received an award for its outstanding efforts to implement the CCMP.

SOURCE REDUCTION

Pollution prevention efforts aimed at ferreting out the sources of specific problem pollutants and reducing their inputs to municipal sewage and stormwater systems continue. Examples from recent years are multifold. In the East Bay, EBMUD pretreatment outreach to radiator shops, dry cleaners, photo processors, electroplaters and other target sources has helped reduce the levels of six metals in the district's discharges. In the North Bay, three oil refineries have been researching and pilot testing selenium source reduction and removal technologies to meet S.F. Regional Board requirements to cut selenium discharges in half by 1998. In the South Bay, community pressure from the CLEAN South Bay Coalition has spawned 112 pollution prevention audits of Silicon Valley metal finishing, disk manufacturing and circuit board industries since 1993. Audits showed metal recovery, rinsewater recycling and other measures could reduce copper and metal pollution by 60-99% and pay for themselves within five years. Since then, with technical and financial assistance from the coalition and local municipalities, many industries have substantially implemented source reduction measures. In 1996, for example, the Palo Alto Regional Water Quality Control Plant helped a number of circuit board manufacturers significantly reduce copper discharges. On a Baywide level, the S.F. Regional Board's 1995 *Basin Plan* update establishes broad new pollution-prevention policy and water-quality-based permit requirements for all counties, POTWs and other local discharging entities. In the Delta region and upstream, metal loads to the Sacramento River have been significantly reduced by construction of abatement facilities at Iron Mountain mine and other sites in the upper watershed.

NEW REGS

Two new Central Valley regulatory programs are now working to reduce two key pollutants — selenium and rice pesticides — in the upper Estuary. In 1997, the Central Valley Regional Board is scheduled to consider new water-quality objectives for five rice pesticides in the Sacramento River. In 1996, the Board established California's first-ever waste discharge requirement with numerical effluent limits on irrigated agriculture, backed up by a 5 ppb selenium objective for the San Joaquin River and an 8,000 lb/year load limit for selenium in discharges from agricultural subsurface drainage systems in the Grasslands watershed. Monitoring since then shows that selenium loads have been somewhat but not substantially reduced. Projects aimed at further reductions are now being implemented.

SPOTLIGHT ON DIAZINON

Several new cooperative groups have formed to work on reducing inputs of the pesticide diazinon in urban and agricultural runoff. On the urban side of the equation, a new coordinating committee of regulators, industry and municipalities was created in 1995. To date, this Urban Pesticide Toxicity Committee has completed reports on the environmental significance, use and application of diazinon and drafted a 3-part strategy for reducing inputs, including regulation, education and further research. On the agricultural side, a state Department of Pesticide Regulation effort launched in 1996 aims to reduce orchard discharges of three dormant sprays (diazinon, chlorpyrifos and methidathion) by encouraging users to independently develop and implement BMPs to reduce spray runoff.

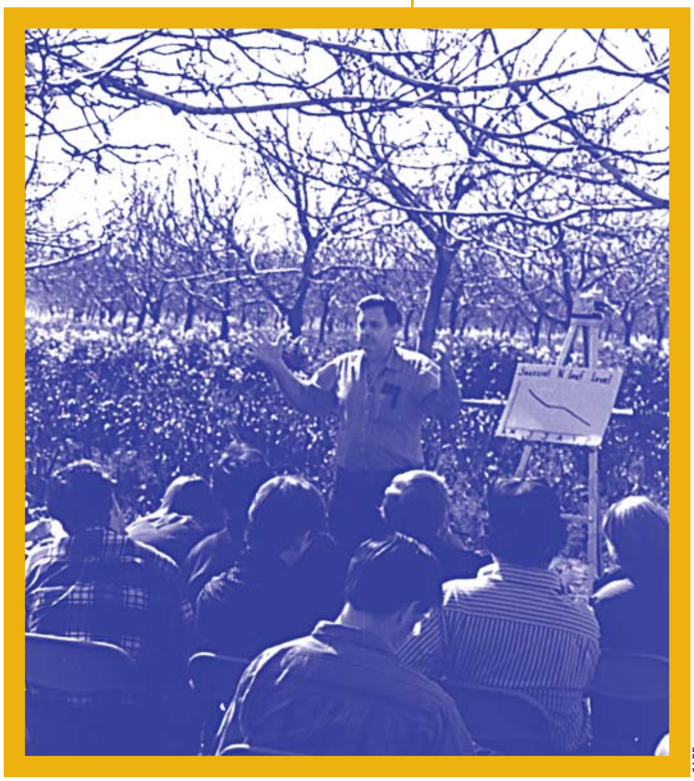
This orchard is one of 72 belonging to walnut and almond growers enrolled in the Community Alliance with Family Farmers '"BIOS" program. Together they farm more than 10,000 acres in seven counties using the chemical-use reduction and other management techniques of the Biologically Integrated Orchard Systems (BIOS) Program. To date, 90% of BIOS almond growers have eliminated the use of insecticide dormant sprays, and overall use of organophosphate insecticides has decreased by 71%. Since joining BIOS, over 75% of growers have established a successful cover crop, 44% have released beneficial insects, 50% have reduced the amount of nitrogen applied to their orchards and 66% have seen an increase in wildlife on their lands. At the 1996 State of the Estuary Conference, the Alliance received an award for its outstanding efforts to implement the CCMP.

DREDGED MATERIAL DISPOSAL

A long-term, multi-agency cooperative effort to balance Bay dredging needs with disposal impacts is nearing completion. Since its inception, this LTMS effort has moved the region away from its past reliance on in-Bay disposal sites (namely Alcatraz) for 90% of dredged material toward a more balanced mix of ocean, Bay and upland sites — minimizing environmental and contaminant risks to any one disposal environment. LTMS research suggests that 80-90% of the estimated 300 million cubic yards of material that needs to be dredged in the next 50 years is clean enough to be suitable for unconfined aquatic disposal in the Bay or ocean, leaving 10-20% needing alternative management. Less than 1% of the material is "hazardous." LTMS has also provided increased clarification of sediment quality assessment protocols and guidelines for suitability for different disposal environments.

MULTI-MEDIA EFFORTS

Recent years have seen increasing recognition that air pollution, transportation systems and uncontrolled urban growth impact water quality. Such recognition has led to some action, including efforts led by Common Ground to reduce the copper content in vehicle brake pads, a 1997 symposium held by the Silicon Valley Pollution Prevention Center in which the impact of traffic on water quality was a major focus, new zoning in Mountain View to concentrate housing and employment near public transit (the city's General Plan explicitly links transportation and water quality), a collaborative effort to match up air and water data on the part of the Bay Area's Regional Board and Air Quality Management District, new monitoring of aerial deposition levels into the Estuary and a Palo Alto public education program that links sparing the air to saving the Bay. Though water quality wasn't the primary inspiration, newly established urban growth boundaries in Santa Rosa, Sonoma, San Jose and other cities and counties promise to reduce runoff and pollution.



CAFF

REGULATORY MONITORING

Launched in 1993 through the CCMP, the Bay Area's Regional Monitoring Program (RMP) currently brings together data from 68 federal, state and local agencies and companies to determine whether the water and sediment quality in the Estuary are in compliance with local, state and federal guidelines and regulations. The S. F. Estuary Institute oversees this information-gathering program in an effort not only to monitor compliance, but also to create a comprehensive picture of pollutant concentrations and effects on the ecosystem and to develop a long-term data base that tracks the seasonal and annual trends in water and sediment quality. The resulting RMP monitors conditions at 24 sampling stations in the lower Estuary. Efforts are now underway to coordinate with pollutant monitoring upstream via new Sacramento River watershed programs and the Interagency Ecological Program. In a separate effort, the Bay Protection and Toxic Clean-up Program has completed screening and testing of 104 potential toxic hot spots in the Bay, with results due for release in spring 1998. Whether the results will lead to any clean up remains politically uncertain.

CITIZEN MONITORING

Citizens are increasingly working with water agencies to monitor creek habitat and conditions. With their help, creek water-quality and environmental data are being collected and fed into water management and regulatory programs for the first time. Protocols for how to do this were developed by the S.F. Estuary Institute in 1996, with support from the State Water Resources Control Board and the S.F. Regional Board. The Bay region now hosts at least 30 community-based creek and watershed programs and three official riparian monitoring stations (Sonoma Ecology Center, Lindsay Museum, Coyote Creek). In the Delta region, ten new citizen monitoring and education efforts are starting up in the Sacramento River watershed and another in the Stockton area.

WATERSHED MANAGEMENT

Watershed management — an approach that involves dealing with all pollutant sources in a single watershed at once — is a new priority for regional, state and federal agencies (see p. 24). Large-scale watershed planning efforts are underway for the Sacramento Basin, the Napa River and the extreme South Bay, with local programs ongoing in at least 30 smaller watersheds in the Bay-Delta region.

CALFED BAY-DELTA PROGRAM

CALFED's (see p. 9) water-quality common program suggests measures such as cleaning up and limiting runoff from problem mines, better managing agricultural drainage and urban stormwater runoff, developing watershed protection programs and providing incentives for fallowing farmfields (with harmful runoff) and for drinking water filtration upgrades. CALFED's ecosystem restoration plan, meanwhile, complements the water-quality common program with its vision for ensuring that all waters of mainstem rivers and tributaries entering the Bay-Delta, and all waters within the Bay-Delta, are free from toxic substances at loads and concentrations that would compromise ecosystem functions, habitats, biological communities or species and the consumption of food species. Such measures will be considered as part of CALFED's three alternatives, soon to undergo environmental impact review.

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5 REFERENCE

SALINITY AND WATER-COLUMN CHEMISTRY

Salinity measurements from continuous monitoring stations located on the Bay Bridge, San Mateo Bridge and Dumbarton Bridge have enhanced our understanding of processes and factors that influence water-column chemistry in the South Bay. Salinity, a fundamental variable in estuaries, is primarily affected by mixing of seawater from the Pacific Ocean and fresh water from the Delta and local streams. This mixing and tide- and wind-driven circulation are primary factors affecting concentrations and distributions of dissolved and particulate substances. During major storms, inflows from local streams can be effective in reducing salinity and concentrations of other substances in the South Bay landward of San Mateo Bridge. These storms typically increase levels of Delta outflow, which lowers salinity near the Bay Bridge within a few days. Large pulses of Delta outflow can affect salinity in most of the South Bay, but this is evident several days to weeks after the nearly immediate effects of local streams. Comparisons of salinity data with a numerical model that simulates seawater-freshwater mixing in the South Bay have identified additional effects of weak tides and even short episodes of strong winds. Weak tides enhance gravity-driven circulation that can rapidly produce large changes in the Baywide salinity distribution. Strong winds mix the water column and also drive large-scale circulation patterns that influence the transport of both dissolved and particulate substances in the South Bay. Together, salinity data and model simulations provide information on circulation and mixing processes that could prove helpful in the interpretation of receiving-water monitoring data in the South Bay (Schemel et al., SOE, 1996).

SACRAMENTO RIVER SEDIMENT

Seasonal and interannual variability in weather and climate are major factors influencing the supply of suspended sediment to the Bay. Most of the annual supply is transported to the Bay during relatively short periods of time, several days to a few weeks during winter when flow in the Sacramento River is highest. At these times, a large fraction of the flow is diverted from the main river channel to the Yolo Bypass to prevent flooding in the Sacramento Valley. During very wet winters like 1983, 1986 and 1995, flow in the Yolo Bypass can be many times greater than that in the main river channel. Measurements of suspended sediment transport from the Yolo Bypass to the Bay are few. At present, we can only estimate its magnitude from river-flow data using flow-sediment-transport relations established from early 1980s data, which show that the Yolo Bypass is the largest source during years with average and higher river flows. During major floods, such as those in 1986 and 1995, the Yolo Bypass over just a few weeks probably transports many times the average annual sediment supply to the Bay. However, relatively little suspended sediment reaches the Bay from the Sacramento River system during drought years or when river flows are low, such as summer and early fall. The supply of suspended sediment to the Bay over the six years of drought following the 1986 flood was probably less than the annual average. Thus, suspended sediment is supplied to San Francisco Bay primarily over short periods of time that might be separated by months to years of very low supply. Particulate carbon (largely organic matter) is an important component of the suspended sediment (about 1-2% by weight). The supply of organic matter from the Sacramento River appears to be an important source of energy for consumer organisms in northern San Francisco Bay, in part because it probably exceeds the annual phytoplankton productivity during average and wet years (Schemel, SOE, 1996).

CLIMATE INFLUENCE ON PHYTOPLANKTON

The density and biomass of phytoplankton diatoms have decreased in the upper Estuary over the past 19 years and were accompanied by an increase in flagellates. Analyses of 19 years of phytoplankton and environmental data indicate that changes in the density and biomass of individual species and groups of species of phytoplankton were associated with the wet and dry cycles produced by climate. These shifts can have a major impact on estuarine ecology because they affect the quality and quantity of food available at the base of the food web. That these changes coincide with the 1977 climate shift indicates that current conditions in the Estuary are part of natural ecosystem succession, and, for future restoration to be effective, it must include consideration of these natural changes (Lehman, SOE, 1996).

FOOD WEB DYNAMICS

As Estuary rivers flow into Suisun Bay, there's a drop in the standing crop of phytoplankton biomass as indicated by chlorophyll at the base of the food web — suggesting heavy plankton mortality. On three cruises of the freshwater-saltwater transition zone in 1994, chlorophyll concentrations and bacterioplankton-specific growth rates were highest in the South Delta's San Joaquin River and decreased by a factor of 2-4 over a salinity range of 0-2 psu, while the concentration of particulate organic material (POM) increased (tripled) as salinity increased over the same range. As a result, the contribution of phytoplankton biomass to POM decreased from about 30% in fresh water to about 5% in the estuarine turbidity maximum (ETM, salinity >2 psu) where river water first mixes with Bay water in the Suisun Bay/Carquinez Strait region. The carbon to nitrogen ratio of particulate material increased from 10 in fresh water to 12 in the ETM — indicating a decrease in food quality. Bacterial production decreased by a factor of about 2 as salinity increased and shifted dramatically from predominantly free-living cells in fresh water to predominantly particle-associated populations in the ETM. These particle-associated bacteria are much more available to filter feeders than free-living bacteria. To increase food availability in the Bay, Estuary managers should take actions favoring increased production of high-quality organic matter in the Delta and delivery of this material to the ETM, rather than to state and federal water projects for export out of the ecosystem (Hollibaugh 1997).

IMPROVED SALINITY-OUTFLOW MODELING

The current salinity-outflow algorithm in the Department of Water Resources Central Valley Operations model (DWRSIM) — the model widely used to simulate the water supply impacts of different Bay-Delta standards and new projects — overestimates the amount of Delta outflow required to meet standards in normal and wet years. In dry years, the model underestimates required flow. To solve this problem, the current algorithm is being replaced with an improved salinity-outflow model. This new "G-model" is based on the 1-D advection-diffusion equation and accounts for previous (antecedent) outflows and tidal dispersion effects. In the proposed new general algorithm, DWRSIM provides previous month's Delta outflow (average), current water-quality standards and QWEST. G-model is then used for each location in the Delta with a water-quality standard. Then the required Delta outflow is determined for each, and the largest outflow governs (Briggs and Denton, SOE, 1996).

MODELING THROUGH-DELTA CONVEYANCE

One of the alternatives currently being considered for "fixing" the Bay-Delta system is a modified through-Delta conveyance system consisting of widened channels and partially inundated Delta islands. Such modifications could provide significant benefits to the Estuary by improving fish habitat, water quality and water supply. As part of the effort, the Contra Costa Water District has modeled a range of possible system modifications using a salinity-transport model — the Fischer Delta Model. Effects of the modifications on waterways are examined through changes in tidal stage, velocity and flow, and the corresponding changes in water quality (Shum et al., SOE, 1996).

HIGH-RESOLUTION VELOCITY MEASUREMENTS

A March-April 1995 field experiment established the accuracy of high-resolution velocity measurements made in the bottom boundary layer (BBL) of the Estuary by a broad band acoustic Doppler current profiler (BB-ADCP). Using a new signal-processing scheme and unconventional mooring design, the BB-ADCP measured current velocity at 5 cm intervals in the bottom 1.6 meters of the water column. The new method is a dramatic improvement over previous techniques in which only a few velocity measurements can be made in the BBL. The high-resolution velocity data in BBL can be used to better define bottom-shear stress, bottom-roughness length and friction velocity. Such measurements are critical for defining mechanisms that control transport, resuspension and deposition of fine sediments in marine environments (Gartner et al., SOE, 1996).

SEASONAL DISTRIBUTION OF JAPANESE FORAMINIFER

The Estuary is the site of the first well-documented introduction of a foraminifer, *Trochammina hadai Uchio*, a microscopic single-celled animal with a calcareous test (shell) which is widely distributed in Japanese estuaries. *T. hadai* apparently was introduced to the Estuary during the 1980s. It is not present in samples collected throughout the Estuary in 1964-1972, nor in 96 surface sediment samples collected at 46 stations in 1980-81. The first known occurrences are in 26 samples collected in 1986 in the South Bay. By August 1995, *T. hadai* was present in sediment from 16 of 22 stations sampled as part of the S.F. Estuary Institute's Regional Monitoring Program. Specifically, it was present at all 15 stations downstream of Davis Point and in the Napa River. It makes up as much as 93% of the foraminifer assemblage in the Central Bay (at Pt. Isabel). Numbers of *T. hadai* in samples collected in February 1996 in the Central Bay near the Golden Gate and along the shipping channel through the North Bay and San Pablo Bay demonstrate the impact of decreased salinity, reflecting high freshwater inflow. At these stations, *T. hadai* abundances are approximately half of the dry-season values. However, in the South Bay, although salinity decreased at all stations in February, *T. hadai* abundances at most stations increased slightly. *T. hadai* apparently prefers more saline conditions, as it does in Japan, where it occurs in open bays and estuaries. It is likely that *T. hadai* was introduced to the Estuary by ocean-going ships. (Sloan & McGann, SOE, 1996).

STORM EROSION AND MARSH SEDIMENTATION

The resuspension of Bay mud by seasonal winds and fluvial sediments generated in a local watershed when major storm events occur had a significant effect on deposition and erosion of sediment in a South San Francisco Bay salt marsh. Sedimentation and erosion were measured from March 1994 to March 1995, in the *Spartina foliosa* that lines Coyote Hills Slough. Rates of sedimentation from 10 to 15 mm/month occurred in spring and summer months when strong northwest winds dominate and cause the resuspension of mudflat sediments. Rates less than 5 mm/month occurred in the fall and winter months when northwest winds diminish. Exceptions to this pattern occurred in January and March 1995 when heavy rains fell. The exceptional rains of January 1995 produced an average sedimentation rate of 27 mm/month. The average yearly rate was 71 to 125 mm/year, depending on elevation. Sedimentation and erosion were also measured in areas where *Spartina alterniflora*, an introduced East Coast species has displaced the native *Spartina*. Patterns of seasonal sedimentation were similar in both species. The sedimentation rates in the *Spartina* zone greatly exceed the current rate of sea-level rise in San Francisco Bay and indicate that salt marshes in the vicinity of Coyote Hills Slough should persist and possibly expand as long as the wind and fluvial-generated (creek) sediment supplies continue (Larsson 1996).

WATERSHED IMPACTS

Freshwater inputs to Bay wetlands from local watersheds may be just as, if not more, important than major river flows from the Central Valley. Analysis of carefully validated historical maps shows strong correlations between aqueous salinity regime and the plan form of tidal marshland at three spatial scales: local (at the tidal source of minor creeks); subregional (along the subordinate estuaries of major creeks and rivers); and regional (along the estuarine gradient upstream of the Golden Gate). As magnitude or proximity to freshwater supply increases, wetlands exhibit lesser channel density, lesser sinuosity of channels, larger drainage divides and larger but fewer ponds. Local creeks strongly influence wetlands at their mouths, suggesting that restoration planners should more carefully consider local watershed inputs (Grossinger 1995).

POST-SPILL WETLAND RESTORATION

Natural restoration of gasoline-contaminated marshes is a viable alternative to invasive clean-up activity. A comparison of vegetation recovery between assisted restoration plots (which received periodic irrigation and removal of weedy upland species), natural restoration sites (left alone) and reference sites (unaffected by gasoline) in the Richmond area showed that, although assistance promoted success of wetland species, the natural approach was not far behind. After one year, wetland plants were thriving in the assisted plots, achieving 94% of total cover, as compared to 60% for the reference plots, and 23% for the natural plots. After two growing seasons, however, the cover on the natural plots compared favorably with that on the reference plots. Another experiment compared planting cordgrass in an insulating mix of sand, peat moss and gravel to placing it directly in fairly contaminated soil. Surprisingly, the petroleum residue didn't affect cordgrass success — all assisted plots approached 100% survival. Such research suggests that the damage caused by people tramping about, trucking in soil and removing vegetation may outweigh the benefits attained in any clean-up effort (Jackson et al., SOE, 1996).

BIOTECHNICAL BANK STABILIZATION

Biotechnical streambank stabilization is a viable alternative to rip-rap that can reduce sedimentation into S. F. Bay while enhancing habitat values. In Petaluma, undercutting and erosion were threatening the site of a proposed shopping mall, a recreational biketrail and an associated riparian habitat restoration project. The City of Petaluma required a biotechnical approach to achieve both erosion control and habitat mitigation objectives. The solution included installation of three rows of 12-inch diameter high-density coconut fiber cylinders to provide protection to the toe of the slope. The top half of the bank was secured by three rows of contour wattling composed of live willow cuttings tied into cigar-shaped bundles averaging five feet in length and eight inches in diameter, and staked end-to-end to form linear rows. Areas in between the rows of wattling and fiber cylinders were secured with 5-inch thick coconut fiber matting. Riparian trees and shrubs were planted only on the top half of the bank to prevent obstruction or diversion of flows. The fiber rolls and mattresses on the lower bank were planted with tules, rushes and other native sod-forming herbaceous species. The stabilized bank withstood severe storm flows the first winter (1993-1994), even prior to establishment of vegetation. During the second winter, installations and plantings remained intact after even greater flow velocities (estimated at over 12 cfs) from floods in January and March 1995, which caused severe erosion on adjacent untreated areas. The treated streambank has now successfully withstood several storm events over four winters (Nichols, SOE, 1996).

HISTORIC MERCURY INPUTS

Mercury has entered the Bay from natural geologic sources, hydraulic gold mining, mercury mining and other industrial sources. A combination of Sr and Nd isotopic compositions and Hg (mercury), Cr and Ni concentrations on Bay cores distinguish among: 1) sediment deposited before any mining activity; 2) sediment released by hydraulic gold mining; 3) sediment deposited when mercury mining peaked; and 4) near-surface sediment. Pre-mining Hg concentrations in the Bay cores are around 0.05 µg/g. Approximately 3.5 x 10^6 kg of Hg were added to sediment in hydraulic gold-mining areas to extract Au (gold) between 1852 and 1884. Mercury concentrations in the Bay cores increased to 0.3-0.4 µg/g after approximately 1850. Higher Hg concentrations occur between approximately 1930 and 1980 when Hg mining remained active, and urbanization and industrialization dramatically increased in the Bay Area (Bouse, SOE, 1996).

BENTHIC FLUX OF TRACE METALS

Benthic flux of trace metals and reactive ligands in the South Bay has been a subject of recent interest because the magnitude of these fluxes, along with other nonpoint sources, can be equivalent or greater than locally regulated point discharges. Processes that control the benthic flux of toxic trace metals and the ligands they react with (e.g., dissolved organic substances and sulfides) are being examined by a number of complementary investigations. Longitudinal gradients for dissolved organic carbon (DOC) predominate in the Estuary, with vertical gradients only observed during periods of salinity stratification. Contrary to the results of previous modeling exercises, measurements by core incubations and *in-situ* flux chambers indicate that benthic fluxes for DOC, dissolved copper and cadmium are temporally variable in direction across the sediment-water interface at both shoal and main channel sampling stations. Although metastable dissolved sulfides in the Bay have a high affinity to react with trace metals, water column data indicate that control of metal speciation (and hence bioavailabilty) by sulfide complexation is likely to be episodic or transient. It is important to quantitatively understand the effects of these nonpoint fluxes, including internal recycling, in order to fully assess the implications of water-quality management decisions. Toward that end, initial benthic flux data is in the process of being incorporated into an existing solute transport model for the Bay (Kuwabara et al., SOE, 1996).

PESTICIDES IN SEDIMENTS

Pesticides associated with sediments are flushed by winter rains into the Estuary, where their accumulation may result in decreased environmental quality, particularly for benthic organisms. Individual pesticides associated with suspended sediments were measured in samples collected from the Sacramento and San Joaquin rivers and Suisun and San Pablo bays. Generally, sediment concentrations of individual pesticides were higher than expected; probably the result of short transit times between agricultural areas and the Estuary. For the San Joaquin River, concentrations varied significantly over the winter peak in discharge. However, suspended sediments collected from Suisun Bay were lower on average in total pesticide content than those collected from either river. These results suggest a substantial variability in the input of sediment-associated pesticides to the

Estuary and that pesticides may be lost from the sediments during their residence in the Estuary. (Bergermaschi, SOE, 1996)

NEW MODELS FOR URBAN RUNOFF ASSESSMENT

Precipitation patterns can substantially influence urban runoff quality. Pollutants build up in urban watersheds during dry periods and are "washed off" into receiving waters to varying degrees during rainfall events. Analysis of the relationships between runoff quality and the precipitation factors related to the build-up and wash-off of pollutants can be used to achieve more accurate estimations of stormwater pollutant loads. When both antecedent (pre-storm) and event-specific rainfall characteristics are analyzed, hydrological variability is considerable from storm to storm and contributes to the high variability commonly found in municipal stormwater monitoring data. Quantifying the sources of this variability is essential to accurate monitoring. Regression models were developed to describe the relationships of Sacramento urban runoff water-quality data with cumulative annual precipitation to date, the number of days since the last storm and storm event rainfall amount. Continuous simulation modeling was then used to determine average annual mass loads from these relationships using the typical (historic) rainfall time series, consisting of 28 years of daily rainfall observations. These methods substantially advance the usefulness of stormwater monitoring data for both calculations of pollutant loadings from urban areas and assessments of long-term trends in discharge quality. The methods can be applied to any urban area with an adequate monitoring data set. This technique has significant implications for management of the Bay-Delta Estuary because it provides a more accurate means of calculating urban runoff mass loadings for comparisons with other pollutant sources to the Estuary (Ruby, SOE, 1996).

SEDIMENT TESTS WITH FISH EMBRYOS

Early embryonic development tests using the estuarine fish species *Menidia beryllina* and *Atherinops affinis* are feasible in *in-situ* sediment toxicity tests. Comparisons between pore-water, SWIC and *in-situ* exposures at a reference site within the Mare Island Naval Shipyard showed no significant difference in hatching success for either *M. beryllina* or *A. affinis* (means + S.E. were 95 + 2, 83 + 1, 92 + 1 and 90 + 2.5, 87 + 2 and 75 + 2.5, respectively). However, hatching success in *A. affinis in-situ* exposures was significantly lower than both pore-water and SWIC exposures at a previously characterized contaminated site (means + S.E. were 62 + 3, 97 + 3 and 92 + 3, respectively). In addition, both species showed a wide range of salinity and temperature tolerances. Pore-water tests were conducted using methods developed in our laboratory, and SWIC tests were conducted using a modification of B. Anderson et al. (1995 In Press in *Techniques in Aquatic Toxicology*). In conclusion, both *M. beryllina* and *A. affinis* embryos may be useful for sediment and *in-situ* toxicity testing in estuarine environments. Their wide temperature and salinity tolerances allow for minimal test manipulations, and both species exhibited excellent hatching success in reference sites for all three types of exposures (Anderson et al., SOE, 1996).

SPATIAL & TEMPORAL VARIANCE

There are a number of reasons to characterize and quantify background levels of sediment contamination in S.F. Bay. These include: creating reasonable targets for restoration efforts, setting sediment guidelines for dredged materials and allowing comparison to potentially contaminated "hot spots." The Bay is a complex system with variations in contaminant levels across geographic regions, years and seasons. Using RMP, Regional Board Pilot Project and Reference Survey sediment data from reference locations, we estimated spatial and temporal (geographic and seasonal) variance components for sediment concentrations of eight metals. For most of the metals, these variances were relatively large. This result indicates that statistics used to quantify background contaminant levels in the Bay must properly incorporate spatial and temporal variation in the data. A tolerance interval approach is recommended (Smith 1995). Analysis of variance (ANOVA) methods, which are commonly used, may be inappropriate. Furthermore, field sampling programs for sediment contaminants should be designed so that spatial and temporal variations can be measured, quantified and used in these statistical models (Riege et al., SOE, 1996).

WATERSHED FRAMEWORK FOR RESTORATION

To effectively restore physical and biological functions to the Estuary, we must first understand the processes by which water, sediment, solutes and biota flow through the system, and how human actions have modified these processes. One of the most fundamental changes has been dam construction above the Central Valley, which has largely isolated the downstream river channels and Estuary from runoff and sediment yield from the upper watershed. This hydrologic discontinuity has important implications. The dams have cut off access to spawning and rearing habitats for salmon, leading to extinction of many runs. The reservoirs have also largely buffered downstream reaches from increased erosion in upstream areas. By trapping sediment, the reservoirs also deprive downstream reaches of gravels important to salmon spawning and invertebrate production. Reservoirs and diversions have also reduced or eliminated floods needed to maintain a dynamic river system and spring flows necessary to send salmon smolts ocean-ward. Adjustment to reduced floods, channelization and land leveling for agriculture have narrowed and simplified rivers, eliminated side channels and reduced riparian vegetation and habitat diversity. With reduced outflows and buffering of runoff from upstream areas, runoff from land areas draining to the Delta and Estuary assumes greater importance to water quality. Given this framework, efforts to reduce nonpoint source pollution should concentrate downstream, efforts to restore salmon should be undertaken with the profound changes in flow regime and channel form in mind, and prioritization of restoration actions should occur on a watershed scale (Kondolf, SOE, 1996).

** Not all the posters presented at the State of the Estuary Conference were submitted for publication (in summary form) in this document. In addition, some poster summaries appear in the body of this report. For abstracts of all the posters, call (510)286-0460 for a copy of the* State of the Estuary Conference Abstract Book.

Conference Presentation and Poster Bibliography

PRESENTATIONS

Baxter, Randall & Dale Sweetnam, CDFG. Status of three sensitive fish species.

Brown, Cynthia, USGS. Effects of chronic metal contamination in Suisun Bay on resident populations of bivalves.

Brown, R., DWR. Introduction to biological resources.

Burau, Jon, USGS. Recent advances in understanding the entrapment zone.

Byrne, Roger, U.C. Berkeley. The influence of climate and sea level rise on wetlands.

Cloern, Jim, USGS. Flow as a linkage mechanism between North and South S.F. Bay.

Coats, Robert, Philip Williams & Assoc. Pollutant loads in urban runoff.

Cohen, A., U.C. Berkeley. The invaded Estuary.

Collins, Josh, SFEI. The geography of wetlands.

Damas, Joe, EBMUD. Treatment and source reduction.

Flegal, A.R. and I. Rivera-Duarte, U.C. Santa Cruz. Water column metal contamination and speciation: trends and implications.

Fry, Michael, U.C. Davis. Organic contaminants and Se: implications for waterfowl in the Bay.

Halat, Kathleen, U.C. Berkeley, and Kathy Hieb, CDFG. Invasion of the Estuary by Oriental and European crabs.

Hollibaugh, James and Patricia Wong, SFSU, and Michael Murrell, U.C. Santa Cruz. The base of the food chain — trends, dynamics and ecology.

Kimmerer, Wim, SFSU. Effects of flow/X2 on fish and invertebrates of the Estuary.

Kondolf, Matt, U.C. Berkeley. A watershed framework for assessing restoration priorities in the S.F. Bay/Delta river ecosystem.

Kuivila, Kathryn, USGS. Dissolved pesticides entering the Estuary from rivers and the Delta and their implications.

Luoma, S.N., USGS, A. van Geen, Columbia University, C. Fuller, M. Hornberger, W. Pereira, F. Hostettler, K. Kvenvolden, and R. Anima, USGS, and A.R. Flegal, U.C. Santa Cruz. Historical basis for assessing the status of contamination in S.F. Bay: contamination trends in sediments and indicator organisms.

McCreary, Scott, CONCUR. Major patterns and major players in regional land-use change.

Mills, Terry, CDFG. Recent trends in the abundance of Central Valley Chinook salmon stocks.

Monroe, Mike, U.S. EPA. Regional wetland goals.

Moyle, Peter and Scott Matern, U.C. Davis. Fish invasions in the Sacramento-San Joaquin Estuary: past, present and future.

Orsi, Jim, CDFG, and Wim Kimmerer, SFSU. Introduced species and their effects on the composition of zooplankton in the northern Estuary.

Schoellhamer, David, USGS. The effects of sediment supply on wetlands.

Spies, Robert, Applied Marine Sciences, Inc. Polynuclear aromatic hydrocarbons in the S.F. Bay Estuary: concentrations and potential effects.

Swanson, J., CDFG and J. Didinato, EBRPD. Wetland restoration and enhancement in North and East Bays.

Thompson, Bruce, SFEI, and Karen Taberski, SFBRWCB. Sediment toxicity in the S.F. Estuary.

Thompson, Janet, USGS. The Asian clam: trends and impacts.

Twiss, Robert, U.C. Berkeley. Watershed planning information on the Web.

POSTERS*

Abu-Saba, K. and A.R. Flegal, U.C. Santa Cruz. Cycling of chromium in the S.F. Bay Estuary: evidence for processes occurring on timescales ranging from minutes to decades.

Anderson, S.L. and J.A. Jelinski, Lawrence Berkeley National Laboratory. Pore-water, epibenthic and *in situ* exposures in contaminated sediments using embryos of two estuarine fish.

Bailey, H., L. Deanovic, K. Luhman, T. Shed, and D. Hinton, U.C. Davis, and V. Connor, CVRWQCB. Pesticides in urban stormwater from the Sacramento Valley and the S.F. Bay Area.

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Bouse, R.M., M.I. Hornberger, and S.N. Luoma, USGS. Geochemical signatures from mercury mining and hydraulic gold-mining in S.F. Bay sediments.

Briggs, D.A. and R.A. Denton, Contra Costa Water District. The effect of improved salinity-outflow relations on Central Valley operations modeling.

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Cacchione, D.A., G.B. Tate, J.T. Ferreira, R.T. Cheng, and J.W. Gartner, USGS. Measurements of flow and suspended particulate transport near the bottom of the main navigation channel in South S.F. Bay, CA.

Cayan, Daniel, Michael Dettinger, Noah Knowles, Marlene Noble, David Peterson, Holly Ryan, Richard Smith, Laurence Riddle, and Reinhard Flick, USGS. S.F. Bay — high Sierra-coastal ocean responses to spring atmospheric forcing.

Clark, R., CDFG Moss Landing, and K. Taberski, SFBRWQCB. Contaminant levels in fish tissue from S.F. Bay.

** Only the 44 primary research posters of the 68 total conference posters appear here (see * p. 57).*

Cole, Brian and James Cloern, USGS. Primary production — a key element to the status of S.F. Bay.

Crepeau, K.L. and K.M. Kuivila, USGS, and C. Foe, CVRWQCB. Pesticides in S.F. Bay-Estuary, California: III. Modifications to the EPA method for aquatic toxicity identification evaluations for target insecticides.
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Hostettler, Francis, Wilfred Pereira, and Keith Kvenvolden, USGS. Preliminary results of geochemical studies of pollutant and natural organic compounds in a reclaimed wetland ecosystem.

Ingram, B. Lynn, U.C. Berkeley, and Ian Hutcheon, Lawrence Livermore Laboratory. Geochemical differentiation of Chinook salmon in the S.F.-San Joaquin Delta: a pilot study.

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Jaffe, Bruce, Richard Smith, and Laura Zink, USGS. Sedimentation changes in San Pablo Bay: 1856-1983.

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Khechfe, A., USGS. Benthic microalgae: its potential as a bio-indicator for determining sediment quality in the S.F. Estuary.

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ACRONYMS KEY

CDFG	California Department of Fish and Game
CVRWQCB	Central Valley Regional Water Quality Control Board
DWR	Dept. of Water Resources
EBRPD	East Bay Regional Park District
SFBRWQCB	S.F. Bay Regional Water Quality Control Board
SFEI	S.F. Estuary Institute
SFSU	S.F. State University
USGS	U.S. Geological Survey

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Estuary Science and Planning Information Online

A number of Web sites now offer imagery, GIS layers, topographic maps, land uses and forecasts, environmental data bases, real-time monitoring, organizational information and clearinghouses, digital libraries and search engines, all of which can help manage Estuary information. For a listing of relevant sites, go to: www.regis.berkeley.edu/papers/tsoe. (Twiss, SOE, 1996)

For the latest Estuary science go to the **Interagency Ecological Program Newsletter** at: http://www.iep.water.ca.gov

For stories on Estuary science, management and education activities 1992-1997 go to **ESTUARY** newsletter at: http://www.abag.ca.gov/bayarea/sfep/newsletter/

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REPORT GRAPHICS AVAILABLE

All maps and charts in this report (except the EcoAtlas) are available in Macintosh- or PC-based digital formats for other uses for a minimal processing fee. (415)258-9199 or email: d@dcampeau.com